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FUNDAMENTALS

OF

BIOLOGY

BY

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PREFACE

The present edition, like the two which have preceded it, aims to present the basic principles common to all living things, with emphasis on those aspects of biology that seem to be of greatest value in contributing to a liberal education. Although the general plan of organization remains unchanged, the addition of new material has both broadened the scope of the book and rendered more thorough the treatment of many topics, particularly those dealing with the animal side of biology.

This book is intended to serve as a basis for an orientation course—to give a broad perspective to the vast field of modern biology. Its objectives are cultural rather than technical, in recognition of the fact that the great majority of students who elect the elementary course do not later specialize in biology. On the other hand, those who do will be provided with a comprehensive view of the science as a whole and with a foundation of knowledge upon which more advanced studies may be based. The book stresses the "unity of life" concept—that, in response to the same natural laws, all plants and animals possess fundamental similarity in bodily organization and in vital processes. Elaborate descriptive details have been largely omitted, the emphasis throughout being placed on fundamental facts and principles.

Over one-half of the book deals with the structure, functions, and classification of both plants and animals, while the remaining portion takes up in an elementary way the more general phases of heredity, adaptation, and evolution. After developing at the outset a number of important concepts and generalizations by a discussion of the cell and of unicellular organisms, four chapters are devoted to the plant kingdom. A survey is made of the lower plant groups, and then the seed plants are considered in greater detail, with emphasis on vegetative structure and reproduction. Next comes an account of vegetative functions and irritability. The succeeding seven chapters deal entirely with animals. First, the important invertebrate phyla are

presented in an ascending sequence, the hydra, earthworm, starfish, mussel, crayfish, and grasshopper serving as types for their respective groups. The ensuing discussion of vertebrates is based largely on the frog. Then follow chapters on animal tissues, metabolic functions, coordination, and reproduction and development. The last part of the book includes three chapters on heredity, two on adaptation, and four on evolution.

In the present edition, the subject of coordination in animals has been expanded into a chapter separate from the one dealing with their nutritive functions, and in both chapters considerable new material relating directly to the human body has been introduced. Vitamins and hormones are dealt with more fully than heretofore, as well as animal tissues. The topic of immunity to disease, as related to man, has been added to a later chapter. Minor changes have been made throughout the entire book, in many chapters on almost every page.

An effort has been made, so far as possible, to develop each chapter as an independent unit. This feature gives the book greater flexibility in permitting the teacher to change the order of topics and to omit material freely without breaking the continuity of the whole. To achieve this result, a slight amount of repetition has been necessary, but it is felt that this is of no disadvantage to the student. The subject matter is presented in a manner simple enough to be easily understood by students in their first year of college work and without any previous knowledge of the subject. Technical terms are reduced to a minimum. The first time a term is used, it is italicized and either defined or explained. This renders the inclusion of a glossary superfluous. The index, which has been carefully prepared, contains all the technical terms used in the text, and definitions are easily found.

Although not absolutely necessary, it is highly desirable that laboratory work be carried on in connection with a study of this textbook, for it is only in the laboratory that a student can obtain a first-hand knowledge of the subject. The author's "Laboratory Directions for General Biology" has been revised to correspond with changes made in the present volume and will be found useful as an adjunct to it.

Many changes have been made in the illustrations, 80 new cuts having been made for this edition. Approximately one-quarter

of the old figures have been replaced by new ones, while, of those appearing in the first edition, about one-half have since been replaced. The total number of illustrations has been increased over the second edition by 11 and over the first edition by 32. All the illustrations not credited to others are original. Acknowledgment of those reproduced from duplicate electrotypes are indicated by "from"; those redrawn from other books by "after." Thanks are due the publishers and authors who have kindly granted permission to use illustrations from copyrighted sources.

The author is grateful to his colleague, Professor Arthur M. Johnson, for assistance in the preparation of many of the illustrations and for kindly making the drawings for Figs. 23*C*, 26, 28, 40, 43, 47, 49, 56, 58, 61, 67, 70, 71, 72, 75, 79, 84, 198, 200, and 209. Drawings for the following figures, all of which appeared in the first edition, were kindly made by Miss Alice Handschiegl: Figs. 86, 105, 117, 118, 119, 124, 127, 132, 133, 134, 163, 196, 197, 202, 204, 205, 206, 207, 208, 213, 214, 215, 216, 217, 225, and 234. The author is also thankful to Mr. Walther B. Schwarz for making drawings for Figs. 89*A*, 89*B*, 106, 108, 109*B*, and 114*B*; also to Mr. Robert C. Stebbins for Figs. 109*A* and 114*A*. All the other original drawings, numbering 90, and the 26 uncredited photographs, were prepared by the author.

The author wishes to express his appreciation of the interest indicated by the widespread adoption the former editions have enjoyed and trusts that the book in its present form may be received as cordially. Suggestions and criticisms will be welcome.

A. W. H.

UNIVERSITY OF CALIFORNIA AT LOS ANGELES,
April, 1940.

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FUNDAMENTALS OF BIOLOGY

CHAPTER I

INTRODUCTION

Biology is the science of life. In its broadest sense, it includes all the facts and principles that have been derived from a scientific study of living things. The multitudinous forms of life inhabiting the earth are infinitely diverse in regard to structural details and life habits, yet nearly all of them can be referred to either the plant or the animal kingdom. Thus the special study of plants, called *botany*, and of animals, called *zoology*, are to be regarded as the two major subdivisions of the larger science of biology. Plants and animals possess a characteristic bodily organization that at once sets them off from minerals, rocks, and other lifeless things. For this reason they are called *organisms.* The type of organization differs in the lower and higher forms of life. Nevertheless, all plants and animals, whether simple or complex, are known as organisms, and all substances, processes, and laws peculiar to them are said to be *organic.*

Although the animate is sharply set off from the inanimate, it is not always easy to distinguish between the two forms in which life commonly exists. Distinctions between plants and animals, based on a study of the higher members of each kingdom, are rather easily made, but when lower forms of life are examined, these distinctions break down. Because of the occurrence of organisms intermediate in certain respects between typical plants and typical animals, the separation of all living things into these two conventional groups is often an uncertain matter. And because even the most highly differentiated plants and animals have many fundamental features in common, it is no exaggeration to say that *all life is one.*

It is commonly supposed by many people who have not studied biology that plants and animals do not manifest the same kind of life. This misconception arises from the occurrence of certain

conspicuous differences between them, such as locomotion and sensitivity. Although most plants are stationary and are slow to respond to external influences, most animals move freely from place to place and exhibit a high degree of sensitivity. But these distinctions are superficial and have nothing to do with the actual state of living. In fact, some of the lower plants have the power of locomotion, while such animals as sponges, corals, barnacles, and oysters do not. Moreover, some plants have sensitive leaves or floral organs that react to stimuli much more quickly than do such sluggish animals as sponges.

Features Common to Plants and Animals.—The distinction between living and non-living things rests upon certain basic similarities in organization and behavior shared by all organisms. These may be stated as follows: (1) Life is always associated with a unique substance, called *protoplasm*, which in all plants and animals is essentially similar in structure, composition, and behavior. (2) This living matter is organized in both plants and animals into microscopic units called *cells*. (3) Certain vital processes, collectively known as *metabolism*, take place in plant bodies in essentially the same manner as in animal bodies. These processes include digestion, absorption, assimilation, and respiration. (4) The property of *irritability*, which is the power of responding to external influences, is common to all living things. (5) *Growth* in all many-celled organisms takes place by a complicated process of cell division followed by cell enlargement and cell differentiation. (6) The essential features of *reproduction* are common to plants and animals. (7) The same *natural laws* apply to all organisms, such as the laws of heredity and evolution.

Scope of Biology.—Living things may be studied from many different aspects, each of which has been organized as a special branch of biology. This has been made necessary for purposes of advanced study because biology, including all organized knowledge pertaining to living things, is too vast a subject to be mastered in its entirety by any one man. Naturally, in an elementary course in general biology, it is possible to consider, in a broad way, only the more basic subdivisions of the subject. These are as follows:

(1) *Morphology*, the study of the form and structure of organisms, is the most fundamental division of biology. It includes a consideration of gross features (*anatomy*) as well as the minute

details that are seen only with the aid of a microscope (*histology*). (2) *Physiology* deals with functions—with vital processes and activities. A study of the functions concerned with metabolism, irritability, growth, and reproduction belongs to the field of physiology. These it seeks to explain, so far as possible, in terms of physics and chemistry. (3) *Taxonomy* is concerned with the naming and classification of organisms and represents the oldest branch of biology. Plants and animals are named according to a binomial system devised by the great Swedish naturalist, Carl von Linné, more commonly known as Linnaeus (Fig. 1). Every

FIG. 1.—Carl von Linné. 1707–1778.

known species of plant and animal has been given a scientific name consisting of two parts. For example, the white oak is *Quercus alba;* the common potato, *Solanum tuberosum;* the dog, *Canis familiaris;* the English sparrow, *Passer domesticus.* Organisms are classified into groups on the basis of fundamental structural resemblance, which indicates natural relationship. (4) *Ecology* is a newer field of biology that takes up the life relations of organisms—their relations to one another and to various factors of their environment, such as light, moisture, temperature, etc. All living things exhibit adaptation to the conditions under which they live. (5) *Organic evolution* is a study of the descent of organisms. It is concerned with the history of life

on the earth and with the structural changes that the various existing species have undergone in the course of their racial development. (6) *Genetics* is a new field that has grown out of the study of evolution. It is concerned with the resemblances and differences between individuals, especially those due to heredity.

Applications of Biology.—An elementary study of biology is given a prominent place in college curricula for several reasons. (1) It is pursued for intellectual gratification. From a purely cultural standpoint biology is of considerable value in giving one an acquaintance with the world of living things, an appreciation of the phenomena of life, and an understanding of some of the great laws and processes of nature. (2) Biology is a necessary prerequisite to further studies. There are many special fields of knowledge that are based largely, or to some extent, on biological facts and principles. These include medicine, psychology, sociology, agriculture, horticulture, forestry, sanitation, dietetics, hygiene, home economics, and many others. Familiarity with, or participation in, any of these fields requires at least an elementary training in general biology. (3) Because man is an organism subject to the same laws as those governing all living things and is built according to the same structural plan as other highly developed animals, an elementary knowledge of biology gives one a basis for an understanding of his own body and thus is a direct aid to health. (4) Plants and animals are of inestimable material value to man, contributing enormously to his welfare and comfort. In fact, they make human life possible. From living things man derives his food. All the nourishment that enters the human body comes from either a plant or an animal source. Man makes his clothing from both plant fibers, such as cotton and linen, and animal fibers, such as wool and silk. Many medicines are derived from plants, while serums, vaccines, etc., come from animals. Wood has always been a building material of first importance. Wood, coal, and petroleum, man's principal fuels, are organic in origin. Scientific knowledge, based on studies of plants and animals, is essential to the most efficient utilization of many of these products.

CHAPTER II

PROTOPLASM AND THE CELL

When a small isolated portion of an ordinary plant or animal is examined with a microscope, it is seen to be composed of a great many minute, organized masses of living matter. These are known as *cells*. Simple types of cells may readily be seen when we look at a piece of a salamander's skin or a drop of its blood, a starfish's egg, a moss leaf, a thin section of a rootlet, or any other favorable material (Figs. 2 and 3). Extensive microscopic examination of the most diverse kinds of plants and animals has demonstrated that cells are the units of which living things are constructed, just as individual stones or bricks may be the components of a wall. Cells are not only units of structure but are also units of function. This means that all vital activities —all the processes that go on in plants and animals—are performed by various kinds of cells. Recognition of the fact that the cell is the unit of structure and function is fundamental to an understanding of much of the subject matter of biology, and so it is appropriate to begin our studies of organisms with a consideration of the cell and of the living matter of which it is composed—*protoplasm.*

A Generalized Cell.—Although there are many kinds of cells in plants and animals, which differ considerably in many ways, all have certain basic features in common. These may be readily seen in Figs. 2 and 3, where several kinds of simple cells are shown. A typical cell consists essentially of a dense spherical body, the *nucleus*, surrounded by a mass of less dense material called *cytoplasm*. Both the nucleus and cytoplasm consist of protoplasm, but each represents living matter of a different kind, the nuclear material being, in general, more complex. The nucleus is enclosed by a delicate *nuclear membrane*, the cytoplasm by a *plasma membrane*. Almost all plant cells have, in addition to the plasma membrane, a thicker covering composed of an organic substance called *cellulose*. This is deposited by the protoplasm

that it encloses and, although not living, is considered part of the cell, constituting the *cell wall.* Because, in plants, the protoplasmic units are separated from one another by partitions of non-living substance, the living matter itself occupies little rigid box-like compartments. In animals, on the contrary, this is not the case. For the most part their cells lack cell walls,

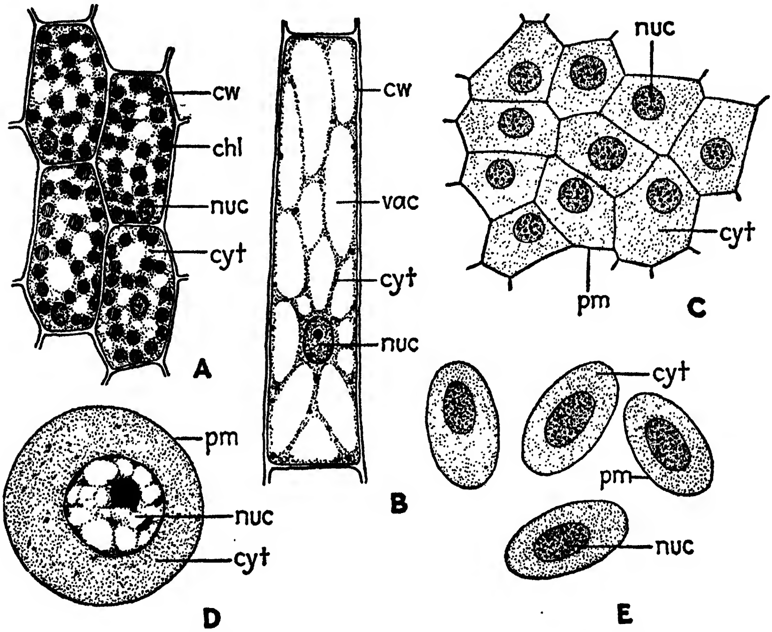


FIG. 2.—Some generalized plant and animal cells. *A*, cells from a moss leaf, × 350; *B*, cell from a hair of a squash leaf, × 150; *C*, piece of the outer skin of a salamander, × 250; *D*, section of an unfertilized starfish egg, × 750; *E*, red blood cells of a salamander, × 500; *nuc*, nucleus; *cyt*, cytoplasm; *cw*, cell wall; *pm*, plasma membrane; *vac*, vacuole; *chl*, chloroplast.

each mass of protoplasm being separated from adjacent ones merely by its thin, living plasma membrane.

Free cells tend to be spherical, but cells in contact with others may be flattened along the sides by mutual pressure, giving them a polyhedral form. This is particularly true of young cells, while older cells generally assume a variety of shapes, often becoming lengthened. Cells also vary widely in size, although nearly all of them are too small to be seen with the naked eye.

Every typical cell contains a nucleus, which consists principally of a fluid, the *nuclear sap*, in which is embedded a coarsely granular substance called *chromatin*. Generally in plant cells, and less commonly in animal cells, one or more small, dense, spherical bodies known as *nucleoli* are also present within the nucleus. The nucleus seems to control the metabolic activities of the cell and plays the principal part in the process of cell division. It is of great importance in connection with heredity.

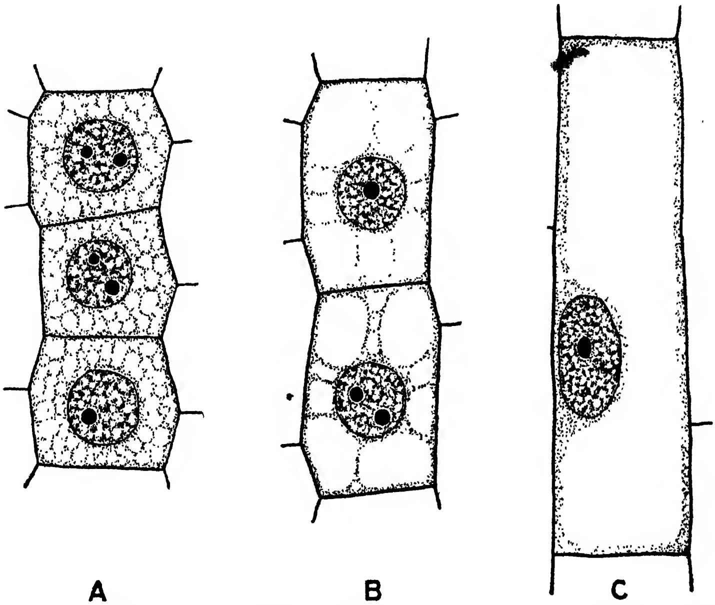


FIG. 3.—Cells from a longitudinal section of an onion root tip, showing the enlargement of vacuoles which accompanies growth of the cell, × 1,000. *A*, young cells; *B*, older cells; *C*, mature cell.

The cytoplasm is finely granular and ordinarily less dense than the nucleus. The minute granules may surround clear spaces called *vacuoles*, which are filled with a fluid designated merely as *cell sap*. Vacuoles are generally larger and consequently more striking in plant cells than in animal cells. In fact, in the latter the cytoplasm often appears essentially homogeneous.

The cytoplasm of very young plant cells is relatively dense and contains many small vacuoles (Fig. 3). As the cell enlarges, the vacuoles coalesce, the nucleus being suspended in the center of the cell by cytoplasmic strands. Finally there is often just

one large vacuole around which the granular portion of the cytoplasm occurs as a thin layer, the nucleus lying against the cell wall. Cells from the green parts of plants, as from a leaf, contain specialized bodies called *chloroplasts.* These are generally small, numerous, and spherical or discoid (Fig. 2*A*). Chloroplasts are dense masses of protoplasm colored by the green pigment *chlorophyll.* They carry on the very important function of *photosynthesis,* whereby the plant is able to manufacture food under the influence of light.

Multiplication of Cells.—Cells exhibit the striking peculiarity of being able to increase in number and thus to reproduce themselves. The formation of new cells is accomplished by *cell division,* a complex process involving first a division of the nucleus and then a separation of the cytoplasm into two parts. Following cell division the protoplasm in each daughter cell increases in volume by the assimilation of food and the absorption of water, thus resulting in *cell enlargement.*

Tissues, Organs, and Systems.—Cells that do not carry on a definite kind of work are most nearly like the generalized cell that has been described. All embryonic cells and a few mature cells are generalized, while most mature cells are specialized for particular functions, and consequently are structurally differentiated. Such a "division of labor" among various groups of cells results in the formation of tissues. A *tissue* is a group of similarly differentiated cells performing one or more particular functions. Wood in plants, and nerve and muscle in animals are examples of tissues made up of highly specialized cells. Cells are organized as tissues in all plants and animals except the lowest, while tissues, in turn, generally are grouped to form organs. An *organ* is merely a differentiated part of the body, such as a root or leaf, or a heart, brain, or stomach. A *system* is a group of organs concerned with some general bodily function. For example, the stomach, liver, and other organs of digestion comprise the digestive system; the heart, blood vessels, and blood make up the circulatory system, etc.

Structure of Protoplasm.—Although by no means identical, protoplasm, the only substance that is alive, is essentially similar in all plants and animals in structure, composition, and behavior. In view of the enormous diversity among organisms, this is a remarkable fact.

Living matter, as seen under the microscope, is usually a semifluid substance, but varies from a jelly-like consistency to that of a viscous liquid. Although nearly colorless, it usually has a slightly grayish tinge, and is also almost transparent. As already noted, protoplasm is nearly always distinctly granular in appearance and usually contains vacuoles of various sizes. On account of its nearly colorless and almost transparent quality, methods of fixation and staining have been devised so that the structure of protoplasm may be seen more clearly. Whether living or properly fixed and stained, protoplasm ordinarily presents an appearance similar to that of a fine colloidal emulsion, the granules being distributed throughout a clear liquid or gelatinous medium which surrounds globules of various sizes, the globules being vacuoles. The liquid inside the vacuoles differs in nature from that surrounding them. Protoplasmic structure can be simulated by adding a small quantity of lampblack to an emulsion of olive oil and water. The carbon particles represent the protoplasmic granules, the oil globules the vacuoles, and the water the medium in which the granules are suspended.

A fact of considerable importance regarding protoplasm is that its constituents form a *colloidal system.* Matter in the colloidal state consists of finely divided particles dispersed through a continuous medium, examples being gelatin, gum arabic, and egg albumen. Colloidal particles, generally representing aggregations of molecules, are sometimes large enough to be seen under the microscope, but are usually ultramicroscopic. They are not so small, however, as the particles in a true solution, which do not exceed one molecule in size, but are smaller than the particles in a suspension. In the case of the colloidal substances present in protoplasm, the dispersion medium is water containing salts and other dissolved substances.

A colloidal mixture may exist either as a *sol,* which is fluid, or as a *gel,* which is semisolid. As a rule, a change from one state to the other can be brought about readily by external conditions, as by a change in temperature. The consistency of protoplasm varies from the sol to the gel state, but is generally more liquid than solid. The colloidal nature of the chief constituents of protoplasm—the proteins—has an important influence on the activities that go on within living cells. The great variety of reactions taking place doubtless arises from the tremendous

complexity and instability of the heterogeneous colloidal system that protoplasm represents.

Composition of Protoplasm.—Although commonly spoken of as "living substance," it must be understood that protoplasm is not a single substance, but a mixture of many different kinds of substances, some of which are chemically simple, others very complex. Protoplasm is somewhat variable in composition, samples from different organisms being essentially similar, but never exactly alike. This variability extends to different parts of the same organism, and even to the same cell at consecutive periods of time. Yet numerous analyses have shown that approximately 97 per cent of ordinary protoplasm consists of four elements that occur, on the average, in about the following proportions: *oxygen,* 65.0 per cent; *carbon,* 18.5 per cent; *hydrogen,* 11.0 per cent; *nitrogen,* 2.5 per cent. The remaining 3 per cent is made up of minute amounts of *sulphur, phosphorus, potassium, iron, magnesium, calcium, sodium,* and *chlorine.* Only rarely are traces of other elements present. It is important to realize that protoplasm contains only a relatively few elements, that these are very common in non-living matter, and that protoplasm contains no elements distinctive of itself.

The 12 elements mentioned above (with the exception of oxygen, which may occur free as well as in combination) always occur in living matter in the form of compounds, and of these there are a great many kinds, both organic and inorganic. The most important compounds—*water, salts, proteins, carbohydrates,* and *fats*—will now be briefly considered.

The most abundant constituent of active protoplasm is water, commonly forming 85 to 90 per cent of its weight. Without this large proportion of water, living matter cannot carry on its ordinary functions. Other inorganic constituents of protoplasm are certain dissolved gases, such as oxygen and carbon dioxide, and dissolved salts, chiefly chlorides, nitrates, phosphates, sulphates, and carbonates. Gases and salts occur only in small quantities.

The most abundant and most important organic substances in protoplasm are proteins of many different kinds. White of egg, lean meat, and the gluten of cereals are examples of substances almost entirely protein in composition. Proteins always contain the four elements, carbon, hydrogen, oxygen, and

nitrogen, but usually sulphur and sometimes phosphorus are present also. Protein molecules are very large and extremely complex, being made up of hundreds or even thousands of atoms. The empirical formula of egg albumen, for example, has been roughly determined as follows: $C_{696}H_{1125}N_{175}O_{220}S_8$. Proteins are so complex that chemists have never been able to analyze any of them satisfactorily. It is known, however, that they are built up from simpler compounds called *amino acids*, the composition of which has been accurately determined in many cases.

In addition to the proteins, protoplasm usually contains other organic compounds, among which should be mentioned the carbohydrates and fats. Unlike the proteins, both of these substances are composed entirely of carbon, hydrogen, and oxygen. Examples of carbohydrates are sugars, starch, and cellulose. Fats differ from carbohydrates in containing less oxygen in proportion to the hydrogen present. When liquid, they are termed *oils*.

The foregoing facts regarding the chemical composition of protoplasm must be accepted with three reservations: (1) When subjected to chemical analysis, protoplasm must necessarily be killed, and thus its composition may be altered. It should be realized that all our knowledge of its composition has been derived from a study of dead protoplasm. (2) The composition of living matter is constantly fluctuating as a result of chemical changes that go on all the time. In fact, the instability of protoplasm is one of its most characteristic attributes. In view of this fact, it is apparent that we can know what substances are present in a given cell only at the particular moment when analyzed. (3) Protoplasm is not merely a collection of various substances, but is undoubtedly an *organization* of substances. This means that its constituents are physically related to one another in ways that are extremely intricate, and that therefore living matter is a system. It is this organization that makes it possible for what we call *life* to express itself. In fact, life may be merely a result of the organization itself.

Behavior of Protoplasm.—It is not difficult to distinguish between animate and inanimate things because we recognize the presence of life by certain sharply defined criteria—by peculiarities in the behavior of living matter. Protoplasm is not only the most complex material in existence, but exhibits a very

remarkable and unique set of properties. These are manifested as follows:

1. Protoplasm has the power of *independent motion*, supposed to result from causes inherent in the living matter itself. In some cases protoplasmic movement results in locomotion, in other cases not. Several types occur, two of which, called amoeboid and ciliary movement, are characteristic of the one-celled animals *Amoeba* and *Paramecium*, respectively. The contraction of muscle and the consequent movement of some part of the body depend upon the ability of special contractile cells to change their shape. In some cases, especially in *Paramecium* and in certain plant cells, a rotation or streaming of the cytoplasm occurs within the cell boundary, but the cell as a whole does not move or change its shape as a result.

2. Protoplasm exhibits *irritability*, which is the capacity of responding to such external influences as gravity, light, heat, contact, chemicals, electricity, and certain others. When stimulated by these influences, various cells react in characteristic ways, as a result of which organisms become adjusted to their environment. Irritability is one of the most distinctive features of protoplasmic behavior, and is just as characteristic of plants as of animals.

3. By the process of *assimilation*, living matter takes up from its environment inanimate substances of varied composition and from them increases its mass. This occurs, not by the addition of layers on the outside (*accretion*), like the growth of crystals in a supersaturated solution, but by the interposing of the new particles among the old ones (*intussusception*), so that they become part of the living organization. It is the property of assimilation that makes growth and reproduction possible.

4. Living matter carries on *respiration*, a decomposition process involving the absorption of oxygen, the liberation of energy, and the formation of waste products. Life without respiration is impossible.

Nature of Life.—Although the preceding criteria enable us to distinguish living from dead objects, regarding the real nature of life, biologists as yet know practically nothing. In fact, it is impossible to define life except in its own terms. Protoplasm, which the famous English zoologist, Thomas Henry Huxley, called the "physical basis of life," is ordinary matter in a peculiar

state—matter with a unique set of properties. There is almost total ignorance regarding the nature of life, because very little is known concerning the causes underlying the behavior of protoplasm. About all that has been accomplished in an attempt to understand the distinctively vital phenomena, has been to observe, measure, and record the ways in which they are manifested in plants and animals.

Regarding the causes of vital phenomena, two theories have been held: the *mechanistic* theory and the *vitalistic* theory. According to the mechanistic conception of life, there is very little difference between animate and inanimate things. It maintains that living matter owes its distinctive properties to the highly complex composition and interaction of the various substances composing it. This theory contends that life is merely the expression of certain physical and chemical laws that still are very imperfectly understood.

The vitalistic view of life is that protoplasm owes its peculiar behavior to the presence of some kind of special force or "vital principle"—that life is something which enters into protoplasm and enables it to function. This "vital principle" has never been identified or analyzed and perhaps from its very nature never can be. Consequently the vitalistic theory is not conducive to scientific investigation, for, if true, it is probably useless to attempt to solve the greatest problem of all time—the nature of life. For this reason, vitalism does not have much support among modern biologists.

It is apparent that the chief point of difference between these two theories is that the mechanists regard life as a result, while the vitalists regard it as a cause. One of the strongest arguments of the vitalists is that protoplasm has never been made artificially in the laboratory. To this the mechanists reply that perhaps some time it will be. It was once thought that all organic compounds could be formed only within the bodies of organisms, as their name itself signifies. But since 1828, when urea was first made synthetically, thousands of different organic substances have been made in chemical laboratories, and each year finds new ones being added to the list. Thus even though there may be such a thing as a "vital principle," it is only by accepting the mechanistic point of view that progress can be made toward a fuller understanding of the nature of life.

Spontaneous Generation.—Because of the great abundance and rapid multiplication of certain forms of life, many strange ideas have been held in the past concerning their origin. One of the most widespread theories has been that of *spontaneous generation,* which has had many supporters, even among scientific men. This idea was prevalent from the time of Aristotle (384–322 B.C.) until the middle of the nineteenth century. It held that many low forms of life can arise directly from inorganic matter or from dead organic remains. Frogs and toads were supposed to develop from mud at the bottom of ponds under the influence of the sun, horsehairs falling into water were thought to give rise to worms, and maggots were claimed to come directly from decaying meat. Many other similar ideas were common.

In 1668, Francesco Redi, an Italian, conducted a set of experiments in an attempt to disprove spontaneous generation. He showed that maggots do not arise from decaying meat *de novo,* but always develop from the eggs of flies deposited there. Redi placed three jars of meat in an open window. One was left uncovered, one covered with gauze, and the third covered with parchment. All the meat decayed, but maggots developed only in the jar which had been left uncovered. Redi observed flies depositing their eggs in the meat contained in the uncovered jar and on the gauze of the second jar, but no eggs were laid on the parchment, because no odors could pass through it to attract the flies.

These and other similar experiments did a great deal toward dispelling the theory of spontaneous generation. But with the invention of the microscope in the seventeenth century, a world of minute forms of life was discovered, and the theory was revived. If a small quantity of hay is boiled and the liquid placed in a covered vessel, great numbers of microorganisms soon appear. These were seen with the microscope, and it was rather naturally thought that they arose directly from the decaying organic matter in the "hay infusion." Several investigators attempted to disprove the spontaneous origin of these minute forms of life by showing that they enter from the air, but their efforts met with only partial success. It was not until 1864 that the theory was completely overthrown. It was then that the great Frenchman, Louis Pasteur (Fig. 4), by a series of very careful experiments, demonstrated conclusively that microorgan-

isms do not appear in sterilized organic matter, even if exposed to air, provided that the air is entirely free of dust. In one of his experiments, he boiled liquids containing material capable of yielding microorganisms, and then admitted air to them after filtrating it through cotton. Since no decay resulted, this proved that dust particles carry microorganisms to the liquids. As a result of Pasteur's experiments to disprove the theory of spontaneous generation, he laid the foundations for the great biological

FIG. 4.—Louis Pasteur, 1822–1895.

science of bacteriology and became one of mankind's greatest benefactors.

There is now no reliable scientific evidence that living things, as we know them, ever arise by spontaneous generation. As far as we can tell, protoplasm comes only from antecedent protoplasm. *Omne vivum ex vivo.* Every kind of plant and animal originates from preexisting individuals of its own kind, and life presents an unbroken chain from the beginning. In regard to the origin of the first forms of life, there is no scientific evidence whatsoever. Nothing is known as to how the first protoplasm came into existence. The origin of life, like the nature of life,

is an unsolved problem, the secret of which science may or may not be able to reveal at some future time.

The Cell Principle.—The fact that the cell is the fundamental unit of all plant and animal structure has been recognized only since 1839. The discovery of cells was made much earlier, however, being credited to the Englishman, Robert Hooke, who first described them in 1665. He perceived with a simple microscope of his own manufacture, that ordinary bottle cork is composed of minute compartments to which he gave the name of cells. Cork tissue forms the outer bark on old stems, commercial cork coming from a species of oak. It consists entirely of dead cells, the protoplasm having completely disappeared and left only the cell walls. Although Hooke saw and described empty cells, the meaning of the term he introduced has been gradually extended to include the protoplasm as well, and where no cell wall is present, the protoplasmic unit itself is called a cell.

Other observers saw and studied cells in many kinds of organisms, but their importance was not appreciated for nearly 175 years after Hooke's discovery. It was then that the "cell theory" was announced, based on the thorough investigations of two Germans, Matthias Schleiden and Theodor Schwann, who claimed that all organisms are composed of cells. Schleiden established the cell theory in the plant kingdom in 1838, Schwann in the animal kingdom the following year. Subsequent investigators have fully substantiated their results, so that today the cell theory is a fully established biological principle. An important addition has been made to it, however, which should be recognized. The essential feature of the cell theory of Schleiden and Schwann was that the bodies of all plants and all animals are made up entirely of cells. To this statement must now be added, "and their products," because it is apparent that much of the material in the bodies of the higher organisms consists of substances formed by cells but not themselves living, as for example, wood and cork in plants, shells and hair in animals, the outer part of the skin, mineral matter in the teeth and bones, the fluid portion of the blood, etc.

The earlier investigators considered the cell wall to be the most important part of the cell, while the contents were regarded as unessential and were largely ignored. This is shown by the retention of the word "cell" itself, indicating a box-like compart-

ment, as a cell in a prison. The Frenchman, Felix Dujardin, was the first to appreciate the importance of the cell contents and to give a name to the living substance. In 1835, he applied the term *sarcode* to the material composing the bodies of microscopic animals, but thought it limited to them and did not regard it as the basis of life. In 1846, the German botanist, Hugo von Mohl, gave the name *protoplasm* to the living contents of plant cells, although it had been used earlier in a different sense. It was not until 1861, however, that the work of Max Schultze, another German, established the similarity between the living matter of both plants and animals. Since that time the term protoplasm has been applied to all living matter.

CHAPTER III

UNICELLULAR ORGANISMS

In the preceding chapter, cells have been considered as structural units composing the bodies of many-celled plants and animals, but among the lowest organisms cells can carry on an independent existence and thus live entirely apart from other cells. Therefore a cell may be merely a minute part of an organism, or it may exist as a separate organism in itself. This means that a plant or an animal may consist of many cells or of just one cell. The lowest forms of life are *unicellular*, each individual being a single unit of protoplasm. Obviously, this represents the simplest possible condition of structural organization, and yet a single cell, living alone, is a complete individual. It can carry on all of the functions that multicellular individuals perform, although doing its work in a much simpler way. Several kinds of common, representative types of unicellular organisms will now be discussed, and the resemblances and differences between them noted.

Protococcus.—There is often present on the shaded side of damp tree trunks, rocks, walls, etc., a bright green stain. If we scrape off a bit of this material, mount the scraping in a drop of water, and examine with a microscope, we see innumerable small, spherical, green cells averaging about 1/2,500 inch in diameter. Each cell is an individual plant—a complete, independent organism. This plant, known as *Protococcus viridis*,[1] is one of the simplest forms of plant life (Fig. 5).

Each cell consists of a mass of cytoplasm surrounding a small central nucleus and enclosed by a cell wall composed of cellulose. In the living condition, the nucleus is difficult to see. The green coloring matter, called *chlorophyll,* is a pigment that appears to be uniformly diffused throughout the cytoplasm, but in reality is confined to a single large peripheral chloroplast, the limits of which are difficult to make out in the living cell. In the presence

[1] Often called *Pleurococcus vulgaris*.

of light and by virtue of its chlorophyll, the cell carries on a very important function—the manufacture of sugar. It makes sugar by combining two very simple inorganic substances: water and carbon dioxide. Not only *Protococcus*, but all green cells, when illuminated, can carry on this process. The making of sugar in a green cell under the influence of light is called *photosynthesis*. It is one of the most important processes in nature.

The sugar made by the cell is used as a source of nourishment; that is, it is assimilated by the living protoplasm. Thus the presence of chlorophyll enables *Protococcus* to make its own food, and this ability it shares with all green cells. The inorganic

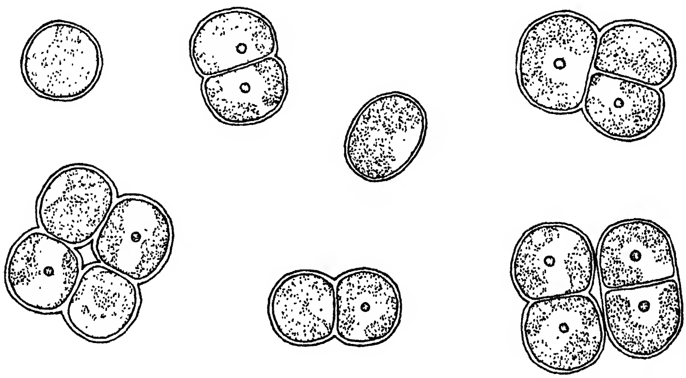


FIG. 5.—*Protococcus viridis*, a simple one-celled plant, × 1,000. Some of the cells have divided to form small groups of cells. Each cell contains a nucleus, cytoplasm, and a single lobed chloroplast.

substances from which sugar is made, *viz.*, water and carbon dioxide, are both absorbed through the cell wall. The cell also absorbs oxygen, a substance that enables it to carry on respiration. This is an energy-releasing process that goes on constantly in all living cells and is entirely distinct from photosynthesis, which proceeds only in the daytime and only in green cells. These two processes should not be confused.

Protococcus not only performs the strictly metabolic processes of photosynthesis, assimilation, and respiration, but like all other organisms it also carries on reproduction. New individuals come into existence by a method called *fission*. After a cell has reached a certain definite size, if external conditions are favorable, it undergoes division into two cells. First the cell elongates slightly and its nucleus divides. Then a cell wall forms between

the two nuclei, cutting the cell in half. The two new cells now increase in size, and either immediately separate, or frequently remain together until each has again divided. Thus from a single individual a group of four cells may arise, sometimes even more, but separation usually occurs shortly after division, each cell taking up an independent existence. Fission is the simplest method of reproduction. It merely involves an approximately equal division of an individual into two new ones that become independent organisms.

Yeast.—There are a number of kinds of yeasts, one of the commonest, called *Saccharomyces cerevisiae*, being used in making bread. Like *Protococcus*, the common yeast plant is unicellular,

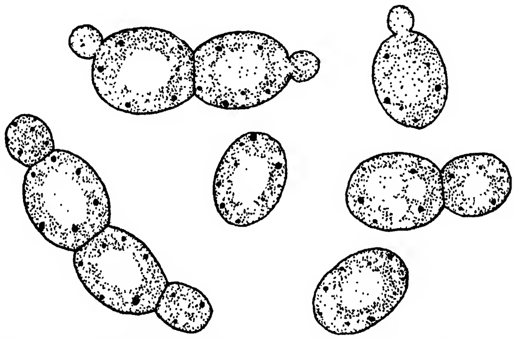


FIG. 6.—Yeast, a unicellular colorless plant, × 1,500. Reproduction occurs by budding, short chains of cells being formed.

but is ovoid in form and about 1/3,000 inch in length (Fig. 6). It has a nucleus, cytoplasm, and a thin cell wall composed of cellulose, but there is no chloroplast, the cell being entirely colorless. Each cell contains one or more large vacuoles and many small oil globules. The nucleus is very small and not visible in the living, unstained condition. Reproduction occurs by *budding*, a modified form of fission. A bud arises as a small outgrowth, usually appearing at one end of the cell. The nucleus divides to form two nuclei, one going into the bud. The bud now enlarges and becomes pinched off from the parent cell; it may either separate at once or remain attached and produce another bud. In this way short chains may be formed, each arising from a single cell. Soon the chains break up, each cell carrying on a separate existence.

The yeast plant lives in fruit juices and other sugar solutions. It resembles *Protococcus* in utilizing sugar as a source of nourishment but differs in that it cannot make its own food. Lacking chlorophyll, it is unable to carry on photosynthesis. It simply lives on sugar that is already made, absorbing it in solution through the cell wall. *Protococcus* is said to be an *independent plant* because it has the power of making its own food and is thus self-sustaining. Yeast is a *dependent plant*, requiring an external source of food. Because it lives on dead organic matter, taking in its food by absorption, it is called a *saprophyte*. Yeast cells use as food only a very small proportion of the sugar that they

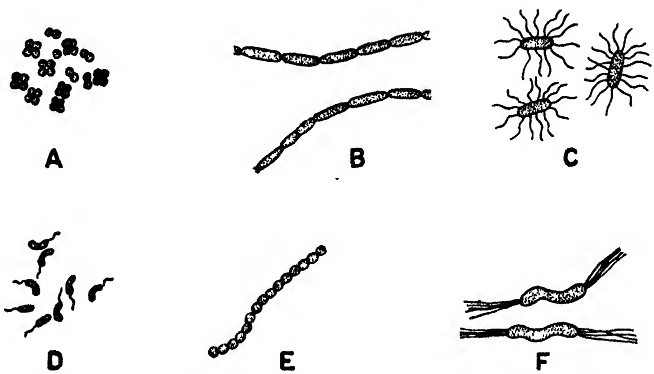


Fig. 7.—Group of common bacteria, × 1,500. *A, Sarcina lutea; B, Bacillus subtilis; C, Bacillus typhosus; D, Spirillum cholerae; E, Streptococcus pyrogenes; F, Spirillum undulatum.*

absorb. The rest is broken down into carbon dioxide, ethyl alcohol, and small amounts of other substances. This process is called *fermentation.*[1]

Bacteria.—The bacteria are at once the smallest and the simplest of all known organisms. They are found under all conditions where life may exist—in fresh and salt water, in soil, in the air, and in the bodies of other organisms. They are of tremendous importance to man, not only because of their relation to disease but because of their beneficial activities as well. Bacteria are unicellular plants lacking chlorophyll and live, for

[1] Fermentation in yeasts is accomplished by the production of an enzyme called *zymase.* It is most active in the absence of free oxygen and serves as a means of releasing energy when the ordinary type of respiration cannot be carried on.

the most part, either on dead organic matter as saprophytes, or on other living organisms as parasites, in both cases absorbing food directly through the cell wall as in the yeast plant. Their cells are of three general types: spherical (*coccus*) forms; rod-shaped (*bacillus*) forms; and curved or spiral (*spirillum*) forms (Fig. 7). Some are non-motile, while others bear slender protoplasmic threads called *cilia*, by means of which they move very rapidly. The rod-shaped types average about 1/10,000 inch in length, while some of the spherical forms are only 1/50,000 inch in diameter.[1] It would take 625 of the former and 3,125 of the latter, placed end to end, to stretch across the head of an ordinary pin, which is approximately 1/16 inch in diameter.

The cells of bacteria are so simple that they might almost be said to be structureless. A thin cell wall surrounds a mass of homogeneous protoplasm. There is no organized nucleus, but merely some scattered granules of chromatin. Bacteria reproduce entirely by fission. In some forms the two cells separate after division, while in others they remain together permanently to form chains, plates, or irregular masses. Such groups of individuals are called *colonies*. Under favorable conditions cell division may occur as frequently as every 20 minutes, so that, in the course of 24 hours, a single bacterium may give rise to billions. Such a rate of multiplication is soon checked, however, by the exhaustion of the food supply or by the accumulation of poisonous waste products of metabolism. While all bacteria are active only in the presence of moisture and other favorable conditions, if these fail, many bacteria can pass into a resting stage, remaining inactive for a long time. Bacteria present on dust particles in the air are in a dormant state and can resist drying and great extremes of temperature.

Amoeba.—This is one of the simplest types of unicellular animals. There are a number of species of *Amoeba*, the best-known one, commonly called *Amoeba proteus*, being widely distributed in stagnant water (Fig. 8). Its body consists of a single colorless cell, irregular in outline because of numerous temporary, finger-like lobes extending in all directions. It is a

[1] Some organisms, whose existence is known only by the effects they produce, are still smaller—too small to be seen with the most powerful microscopes. In fact they even pass through the pores of a porcelain filter, and for this reason are called *filterable viruses*.

relatively large cell, being about $\frac{1}{100}$ inch in diameter, but most other species are considerably smaller. As in a typical animal cell, there is a nucleus surrounded by cytoplasm, a very thin plasma membrane on the outside, while a cell wall and chloroplasts are lacking. The nucleus is rather difficult to see in the living condition but is very distinct after the cell has been killed and stained, when it is seen to consist of many coarse granules. With the exception of a comparatively thin layer on the surface, which is clear, the cytoplasm is finely granular. The outer clear layer is known as *ectoplasm,* the central granular mass as

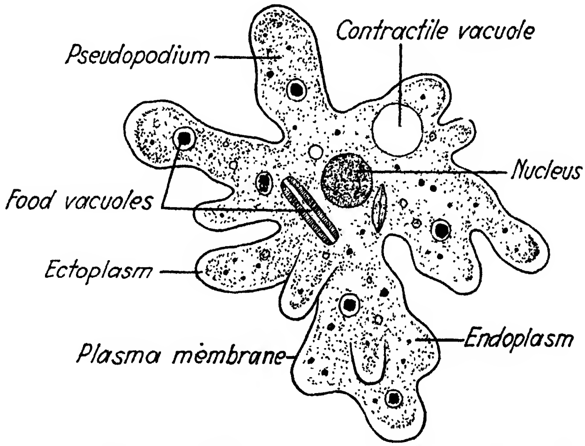


FIG. 8.—*Amoeba proteus,* a simple unicellular animal, × 250.

endoplasm. A large clear *contractile vacuole* is present in the cell. It suddenly contracts and then slowly expands, this action taking place regularly at short intervals.

The finger-like extensions of the cell, termed *pseudopodia,* are the means by which locomotion is accomplished. When the animal is active, its outline is continually changing because of the extension and withdrawal of these finger-like lobes (Fig. 9). When one or more pseudopodia are thrust out in a given direction, the cytoplasm is seen to flow into them, and at the same time other pseudopodia are retracted. As a result of this behavior, the animal slowly moves from place to place. The flowing of the cytoplasm is a very striking thing to observe, and is a beautiful demonstration of the power of independent motion,

which has been mentioned as one of the unique features of living matter.

The food of the amoeba consists of unicellular green plants, bacteria, other smaller animals, and of dead vegetable and animal matter. As the animal slowly creeps along, it may come in contact with a food particle. It then thrusts out pseudopodia, which surround the food, flow together, and engulf it. A small amount of water is taken into the cell with the food particle, forming a *food vacuole.* The work of digestion now begins.

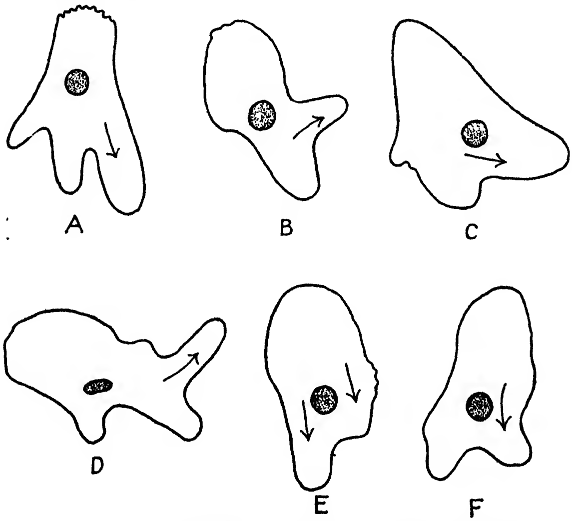


Fig. 9.—Locomotion in *Amoeba.* *A, B, C, D, E, F,* outlines of a moving individual sketched at intervals to show the formation and withdrawal of pseudopodia. (*After Calkins.*)

Digestive fluids pass into the food vacuole from the surrounding cytoplasm, and the food is gradually changed chemically in such a way that it can be absorbed and thus made part of the living cell. This is the process of assimilation that we have seen to be characteristic of all living matter. The digested food material, by assimilation, increases the amount of protoplasm in the cell. Indigestible matter is expelled from the body at any part of its surface, being merely left behind as the animal moves on.

As in one-celled plants and all other living cells, oxygen is absorbed from the surrounding medium in order that the process of respiration may go on, for otherwise life cannot exist. The

oxygen combines with the protoplasm with the result that energy is liberated, just as when a piece of coal is burned. The oxidation of organic matter in the cell causes metabolic waste products to be formed. These are chiefly water, carbon dioxide, and urea. Urea is a nitrogenous substance resulting from the decomposition of proteins. Much of this waste matter passes out of the cell directly through the plasma membrane, while some apparently flows into the contractile vacuole and is expelled by it through the plasma membrane into the surrounding water. Thus this structure plays a part in the work of excretion. It also serves as a means of getting rid of excess water taken into

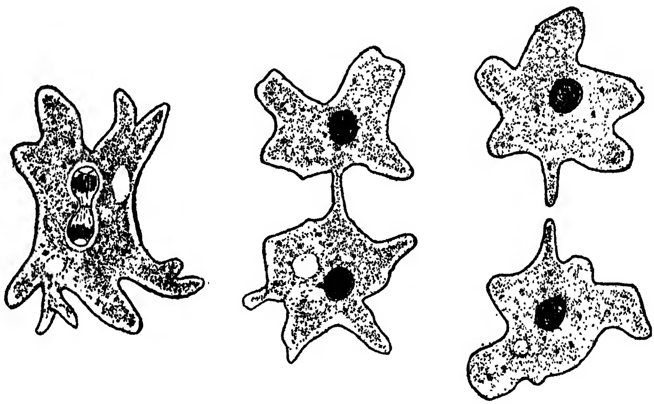


FIG. 10.—Fission in *Amoeba*, showing the division of the nucleus, constriction of the cytoplasm, and separation of the two new cells. (*From Shull, "Heredity."*)

the cell. When an active amoeba is touched with a solid object, it reacts by moving in the opposite direction. Similarly it moves away from an irritating chemical, from heat, or from strong light; but, if food is near, the animal usually moves in its direction. These responses are manifestations of irritability.

If the amoeba gets plenty of food, more protoplasm is built up by assimilation than is destroyed by respiration, and as a result growth takes place. A size limit is soon reached, however, beyond which the animal does not go, and then reproduction occurs. The amoeba, like most other unicellular organisms, reproduces by fission, the cell dividing into two parts, each of which takes up an independent existence (Fig. 10). First the nucleus divides to form two nuclei. Then these move apart, and

between them the cytoplasm gradually becomes constricted into two approximately equal parts that finally separate to form two new cells.

A curious fact about one-celled organisms is that, although the cell may die through accident, natural death does not occur.

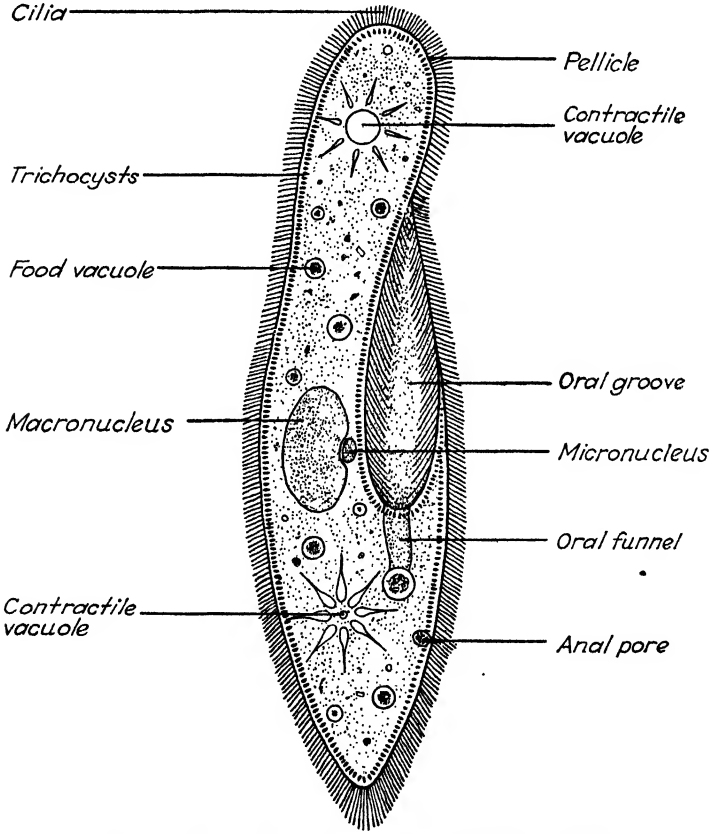


FIG. 11.—*Paramecium caudatum*, a unicellular animal.

Each individual is potentially immortal, as reproduction by fission takes place before old age is reached. In the presence of adverse conditions, as during a drought, the animal passes into a quiescent state, becoming spherical and secreting a protective layer around itself. Such an individual is said to be *encysted*. It remains in this state until revived by the return of favorable conditions.

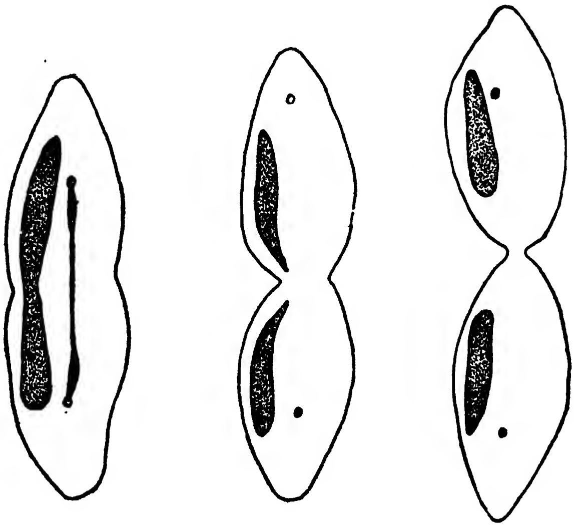
Paramecium.—This is a more complex unicellular animal than the amoeba, but like it is common in stagnant ponds and streams (Fig. 11). It is also a large form, being about $\frac{1}{125}$ inch long. In fact, a single individual is just barely visible to the naked eye when seen against a black background. Owing to the presence of a firm outer membrane called the *pellicle*, the cell has a definite and constant form, but there is no cellulose cell wall. One of the commonest species, *Paramecium caudatum*, is more or less slipper shaped, being rounded at the *anterior* (forward) end and pointed at the *posterior* (rear) end. The cell is entirely covered over with very short, fine, protoplasmic threads called *cilia*, which beat against the water and rapidly propel the animal forward. Thus the method of locomotion in *Paramecium* and *Amoeba* is very different.

Paramecium does not take a straight course through the water, but swims in a spiral path, at the same time rotating on its long axis from right to left (Fig. 12). Ordinarily the animal swims with the rounded end forward, but under special circumstances, as when an obstacle or an irritating substance is encountered, the cilia reverse their action and send the animal backward. A new course is now taken, but if the unfavorable stimulus is again encountered, the same avoiding reaction is repeated until a clear path is found. This type of behavior, called the *trial and error* method, may easily be observed if living animals are available for study.

In cell structure *Paramecium* differs in several ways from *Amoeba*. Two nuclei are present: a large oval *macronucleus* and

FIG. 12.—Diagram showing spiral path taken by a paramecium and rotation on its long axis from right to left. 1 to 4, successive positions. The shaded areas represent currents of water drawn into the oral groove. (*From Jennings, "Behavior of the Lower Organisms," Columbia University Press, by permission.*)

a small spherical *micronucleus.*[1] These are in contact with each other and have a constant position near the center of the cell. The cell also contains two contractile vacuoles, one located at either end. Usually these alternate in contracting at intervals of about 10 to 20 seconds. Extending radially into the cytoplasm from each contractile vacuole are a number of minute canals. These seem to collect liquid waste products, which are



A B C

FIG. 13.—Fission in *Paramecium*, showing successive stages in the division of the macronucleus and micronucleus, and in the constriction of the cytoplasm.

emptied into the vacuole and finally discharged to the outside. The contractile vacuoles also relieve the cell of excess water.

In the anterior half of the animal is a shallow depression called the *oral groove,* which extends diagonally backward from left to right. At its lower end is a funnel-like opening into the cytoplasm termed the *oral funnel.* The oral groove is lined with long cilia whose beating creates currents that sweep food particles, consisting of bacteria and smaller one-celled animals, into the lower end of the oral funnel. A number of food particles enter the cell in a drop of water, forming a food vacuole. This breaks loose from the end of the funnel and passes into the cytoplasm.

[1] *Paramecium caudatum* has one micronucleus, but some species have two micronuclei, and some have several.

By a streaming movement of the cytoplasm, the food vacuoles pass to other parts of the cell, following a definite course. The processes of digestion, assimilation, respiration, and excretion are carried on in essentially the same way as in *Amoeba*, but in *Paramecium* there is a definite spot on the surface of the body, called the *anal pore*, where indigestible matter is expelled. This is situated directly behind the lower end of the oral funnel.

A peculiar feature of *Paramecium* is the presence of numerous specialized, sac-like structures in the outer part of the cell (the ectoplasm) just beneath the pellicle. These are *trichocysts.* When stimulated, they discharge into the water long hair-like threads that form a protective network and tend to keep away another animal attacking the paramecium. Reproduction occurs by fission (Fig. 13).[1] Both the macronucleus and the micronucleus elongate and divide, each forming two daughter nuclei. At the same time the cytoplasm constricts transversely and finally separates into two halves. One cell has the original oral groove and oral funnel, while the other half develops these structures anew. A second contractile vacuole arises in each daughter cell. The two individuals formed by fission increase to the size of the original cell, when each may again undergo fission.

Vorticella.—Another common unicellular animal, living in ponds and ditches, is *Vorticella*, a form related to *Paramecium*, but showing certain interesting differences as a result of its peculiar mode of life. The body of *Vorticella campanula* is bell-shaped (Fig. 14). It is attached to an object in the water by means of a long contractile stalk. Around the upper margin is a row of cilia, and extending inward is a deep oral groove also bordered by cilia. Since the animal is not free swimming, the cilia are not used in locomotion, but by their rapid beating create a vortex into which currents of water are drawn. As in *Paramecium*, the oral groove leads to an oral funnel where food particles (chiefly bacteria) accumulate and finally enter the cell in the form of a food vacuole. *Vorticella* has one contractile vacuole, a small globular micronucleus, and a long U-shaped macronucleus. Indigestible matter is expelled through a definite anal pore that opens into the oral groove. Reproduction occurs by fission, the

[1] The peculiar behavior known as *conjugation* is briefly described elsewhere (see p. 229).

body dividing longitudinally. In the presence of unfavorable conditions, encystment may occur.

Euglena.—Although it is possible to assign most organisms to either the plant or the animal kingdom, there are some low forms of life with mixed affinities, combining characters of both plants and animals. One such group is the *flagellates*, often represented in stagnant pools and ditches by a form known as *Euglena viridis* (Fig. 15). Like *Paramecium* and *Vorticella*, this organism has a rather definite form, owing to the presence of a thin elastic pellicle, but some flagellates are amoeboid, putting out slender pseudopodia. A cellulose wall is not present. *Euglena* is blunt at its forward end, gradually tapering behind. It swims by means of a single long, whip-like cilium (usually termed a *flagellum*), attached anteriorly, that lashes back and forth and pulls the organism through the water. At the base of the flagellum is a red *pigment spot*, which is thought to be sensitive to light, as the organism tends to swim toward the best-illuminated part of the water, although avoiding direct sunlight. Near the pigment spot is a contractile vacuole that opens into a permanent cavity termed the *reservoir*. A single nucleus is present in the posterior part of the cell.

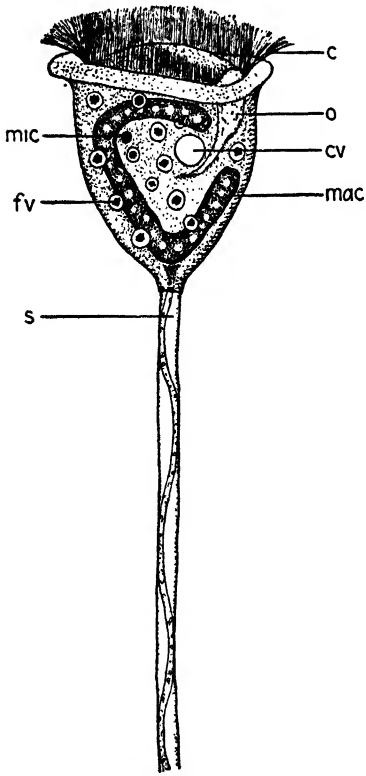


FIG. 14.—*Vorticella campanula*, an attached unicellular animal, × 500. *c*, cilia; *o*, oral funnel; *cv*, contractile vacuole; *mac*, macronucleus; *mic*, micronucleus; *fv*, food vacuole; *s*, stalk.

At the anterior end of the body is a small oral funnel that leads to the reservoir, but, strangely enough, no food is ordinarily taken in through it. Instead of ingesting solid food particles as unicellular animals do, *Euglena* makes its own food, for within the

cell are a number of small chloroplasts that enable the organism to carry on photosynthesis. Thus its nutrition is distinctly plant-like. Reproduction occurs by fission, the cell dividing longitudinally. One half keeps the old flagellum, the other forming a new one. As in *Amoeba* and many other unicellular organisms, encystment in the presence of unfavorable conditions is a common occurrence.

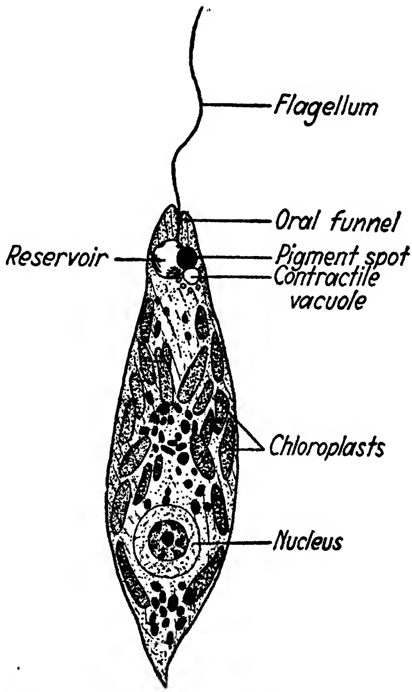


FIG. 15.—*Euglena viridis*, an organism showing both plant and animal characters. (*After Doflein.*)

Although *Euglena viridis* has chloroplasts and carries on photosynthesis, certain other flagellates are colorless. Some forms are parasitic, such as *Trypanosoma*, which causes African sleeping sickness. Other flagellates are saprophytic, absorbing liquid organic matter as the yeast plant does. Some take in solid particles of food through the oral funnel, while others engulf food like an amoeba. Some species of *Euglena* carry on photosynthesis in the light, but if kept in darkness and supplied with organic material, they become colorless and saprophytic.

The occurrence of such organisms as flagellates, intermediate between plants and animals, suggests that the first forms of life may have been similarly undifferentiated, representing a common ancestral stock from which later both plants and animals may have arisen. Thus the relation of flagellates to the two great organic kingdoms may be likened to that of the stem of the letter **Y** to its two branches. Plants became differentiated by

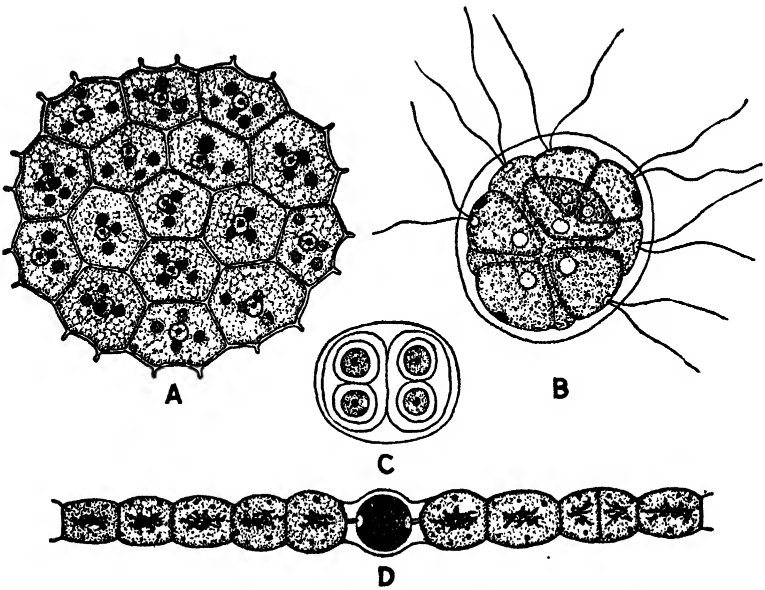


FIG. 16.—Some simple plant colonies. *A*, *Pediastrum*, a plate-like colony with cells in close contact, × 750; *B*, *Pandorina*, a spherical, 16-celled, motile colony enclosed in a mucilaginous sheath; *C*, *Gloeocapsa*, a simple colony, the cells imbedded in a mucilaginous matrix, × 750; *D*, *Anabaena*, a simple chain-like colony with a differentiated cell marking the place where the colony will break, × 1,000. *A* and *B* are green algae, *C* and *D*, blue-green algae. (*B*, *after Pringsheim*.)

emphasizing photosynthesis, storage of energy, rigid tissues, and fixity of position. Animals arose, on the other hand, by emphasizing the acquisition of food from plants, the liberation of energy, flexible tissues, and motility. Each of the distinguishing features of plants and animals is related to the basic factor of nutrition and has arisen in consequence of that primary difference.

Colony Formation.—It has been seen that cell division in unicellular organisms results in the production of two new indi-

viduals. As a rule, these immediately separate, but in such forms as *Protococcus* and yeast, the cells produced by fission show a tendency to remain in contact for a while before separating. Carried further, this tendency would result in the formation of colonies. A *colony* is an aggregation of individuals, each maintaining itself and having little or no dependence upon the others. Thus unicellular organisms may be either solitary or colonial,

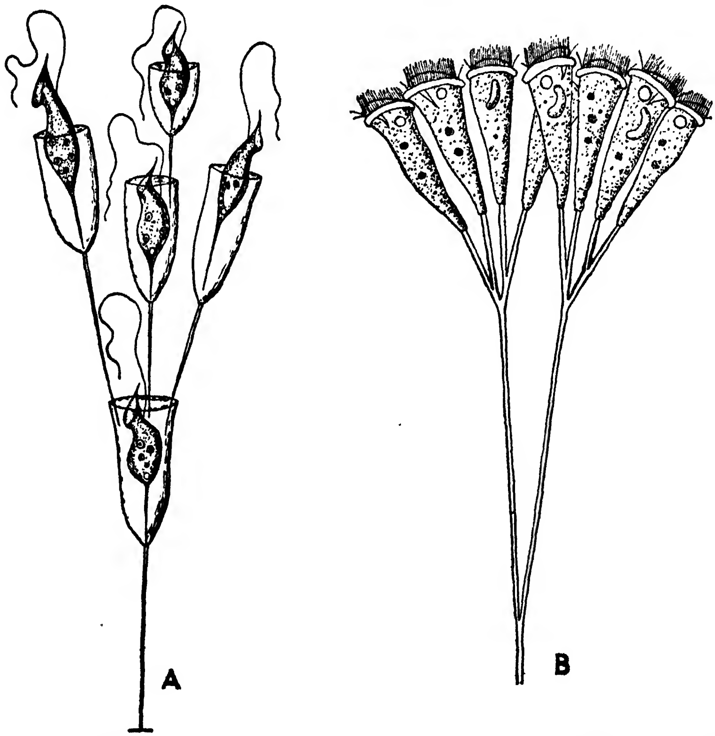


FIG. 17.—Tree-like colonies of unicellular organisms held together by means of stalks. *A*, *Poteriodendron*, a flagellate; *B*, *Epistylis*, a protozoan. (*A*, *after Stein*; *B*, *after Kent.*)

depending on whether the cells separate following division or remain permanently together. Colony formation is rather prevalent among unicellular plants and flagellates, but uncommon among one-celled animals, being confined chiefly to forms related to *Vorticella* (Figs. 16 and 17).

The cells forming a colony may be arranged in chains, filaments, plates, spheres, irregular masses, or otherwise. The

simplest colonies consist of cells held together very loosely by a mucilaginous matrix, by stalks, or by some other mechanical means. In more highly developed colonies the cells are in contact with one another, and so there is organic union between them but no physiological dependence, as any cell may become detached from the colony and continue to maintain itself. Some colonies consist of only a few cells, others of many thousands. As a rule, all the cells in the colony are alike, but in some cases certain cells, with specialized functions, become differentiated.

It is apparent that no sharp distinction exists between the more highly organized colonies of unicellular individuals, on the one hand, and simple multicellular organisms on the other. In fact, any line of demarcation drawn between them would be arbitrary. The fact that unicellular and multicellular organisms intergrade is of great significance, indicating that the latter may have been derived from the former through the formation of colonies. In the evolution of the early forms of life, the tendency for cells to remain together after division led to the development of colonies, while a closer association of the cells in the colony may have led to a dependence of the cells on one another, thus resulting in a multicellular organism.

All the higher plants and animals are multicellular, the individual consisting of innumerable cells closely associated in structure and function. Here each cell is but a small part of the individual. Another feature of multicellular organisms is the fact that the cells of the body cooperate in the performance of their functions and are more or less dependent on one another. It is only under special circumstances that a cell may become separated from the organization and carry on an independent existence; ordinarily this is not possible.

CHAPTER IV

THE LOWER PLANT GROUPS

In discussing organisms of greater structural complexity than the unicellular forms considered in the last chapter, it will be more advantageous to treat of plants and animals separately than to attempt any other plan. Plants will be studied first because they are, in general, simpler than animals.

About 250,000 different species of plants have been named, described, and classified by botanists. This vast assemblage of forms, collectively constituting the *plant kingdom*, includes not only the various kinds of familiar plants of field, forest, and garden, most of which are structurally complex, but also the many simpler ones largely unknown to most people. The plant kingdom is divided into four major groups, the members of each having certain basic features in common, and each succeeding group representing a higher condition of structural organization than those below it. This chapter will be devoted to a consideration of the three lower plant groups, while the two that follow will deal with the highest group.

THALLOPHYTES

The thallophytes constitute a large and diverse assemblage of simple plants forming the lowest division of the plant kingdom. They number about 80,000 species. The plant body may consist of one cell or of many cells (although most thallophytes are multicellular) but in the latter case is nearly always a *thallus*, that is, a plant body with little or no differentiation into distinct vegetative organs, *viz.*, roots, stems, and leaves. It is chiefly to this feature that the thallophytes owe their simplicity. The thallophytes comprise two subordinate groups: the *algae* and the *fungi*. The former number 20,000 species, the latter 60,000.

ALGAE

With respect to their nutrition, algae are independent thallophytes, all of them having chlorophyll. They are the simplest

of all green plants and are thought to be also the oldest. Nearly all the algae live in water, both fresh and salt. They include the pond scums, kelps and other seaweeds, and many less familiar

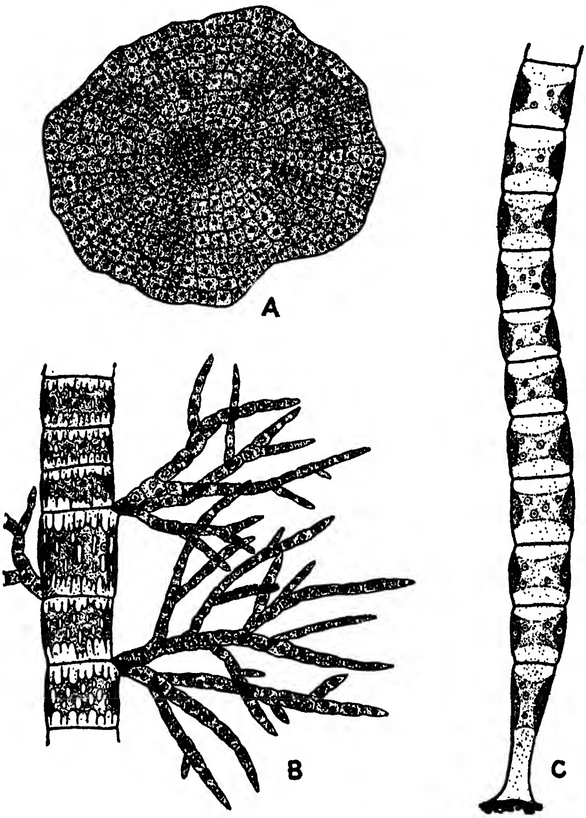


FIG. 18.—Some simple multicellular green algae. *A*, *Coleochaete*, the cells in a plate-like arrangement, × 150; *B*, *Draparnaldia*, a branching filament showing differentiation in size of cells, × 250; *C*, *Ulothrix*, a simple unbranched filament with a differentiated basal cell that serves as a holdfast, × 350. In *B* and *C* the peripheral band-like chloroplast obscures the central nucleus; the small bodies on the chloroplast (pyrenoids) are centers of starch formation.

forms. Many are microscopic, but some of the seaweeds reach a large size.

Vegetative Body.—*Protococcus*, a typical one-celled alga, has already been discussed. Many other unicellular forms occur, some of which are solitary, others colonial. A few of the latter are shown in Fig. 16. Among the simpler multicellular algae, the

body commonly has the form of a simple filament (a row of cylindrical cells attached end to end) or a branching filament, while some algae consist of a thin plate of cells (Fig. 18). In many cases all the cells of the body are essentially alike in form and structure, but often there is a tendency for some of them to become different. For example, one or more cells may be modified to serve as a means of attachment to an object in the water (Fig. 18*C*). In many of the branching forms the cells

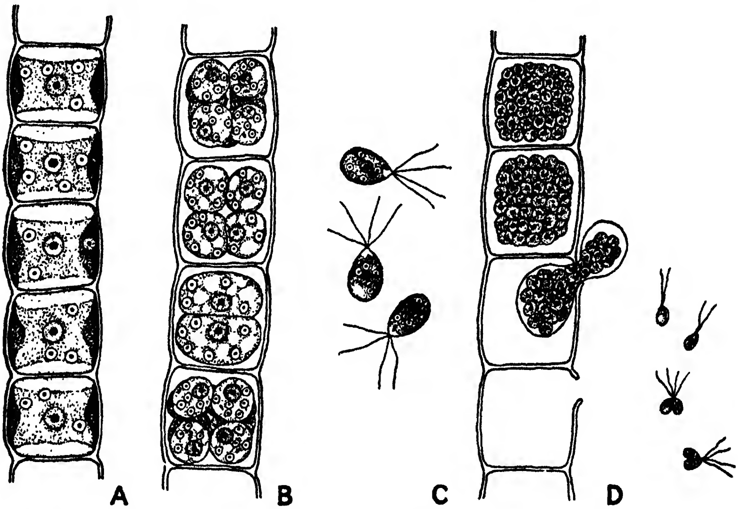


FIG. 19.—Reproduction in *Ulothrix*, a simple green alga, × 700. *A*, portion of vegetative filament. Each cell contains a central nucleus and a peripheral band-like chloroplast with a number of starch-forming bodies (pyrenoids); *B*, formation of spores inside the vegetative cells; *C*, free-swimming spores which have escaped; *D*, formation and escape of gametes, some of which are pairing.

show a differentiation in size, those of the branches being smaller than those of the main filament (Fig. 18*B*). Structural differentiation becomes marked in the higher plants, eventually leading to the formation of tissues and organs. The most highly differentiated algae are marine forms with a body consisting of parts that bear a superficial resemblance to the roots, stems, and leaves of the higher plants, but which structurally are much simpler (Fig. 23*C*).

Asexual Reproduction.—In reproduction, as in vegetative features, the algae are also relatively simple plants. Among the unicellular forms, such as *Protococcus*, the prevailing method of reproduction is by fission—obviously the most primitive method

possible. All cells divide, but it is only among unicellular organisms that cell division results in reproduction. Among multicellular organisms it results in growth, and reproduction takes place by the separation of a cell or a group of cells from the parent, the new individual developing from this fragment. A common method by which this process operates in the algae is by the production of swimming spores.

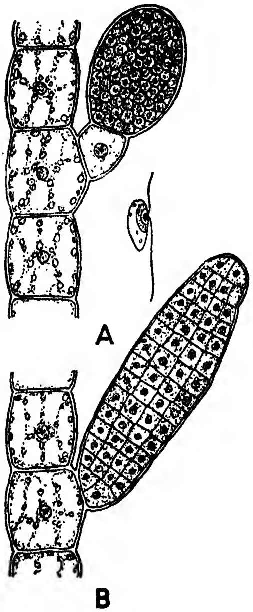


FIG. 20.—Sporangium (*A*) and gametangium (*B*) of *Ectocarpus*, a brown alga, × 400. Also a single escaped spore.

A *spore* may be defined as a cell having the capacity of directly developing into a new plant. In many of the simpler algae, the contents of any one of the vegetative cells may give rise to one or more uninucleate swimming spores (Figs. 19 and 22). These escape from the plant as naked cells (lacking a cell wall) and swim through the water by means of cilia. A fact of special interest in connection with these swimming spores is that many of them resemble flagellates, not only in being naked and motile, but in having a contractile vacuole and a pigment spot (see pp. 30 and 31). After coming to rest, each spore may give rise to a new plant by cell division, this behavior being called *germination.* In many of the algae, spores are produced in specialized structures called *sporangia,* whose sole function is spore production (Fig. 20*A*). Sporangia are characteristic of all plants above the thallophyte level.

Sexual Reproduction.—Sexual reproduction among the lower algae is a relatively simple process. Naked, detached cells called *gametes* are formed; these resemble swimming spores in appearance but are usually smaller (Fig. 19*D*). Although gametes arise in the same way that spores do, they are incapable of directly forming a new plant. Instead of germinating, they come together in pairs and fuse. *The essential feature of sexual reproduction in all organisms is the fusion of two gametes.* The pairing cells become one, and then their nuclei unite. The cell that

arises from the union of two gametes is called a *zygote*. In the algae it usually secretes a heavy wall around itself and goes into a dormant condition, later either giving rise to a new plant directly, or to four spores, each of which in turn produces a new plant (Fig. 22*F*).

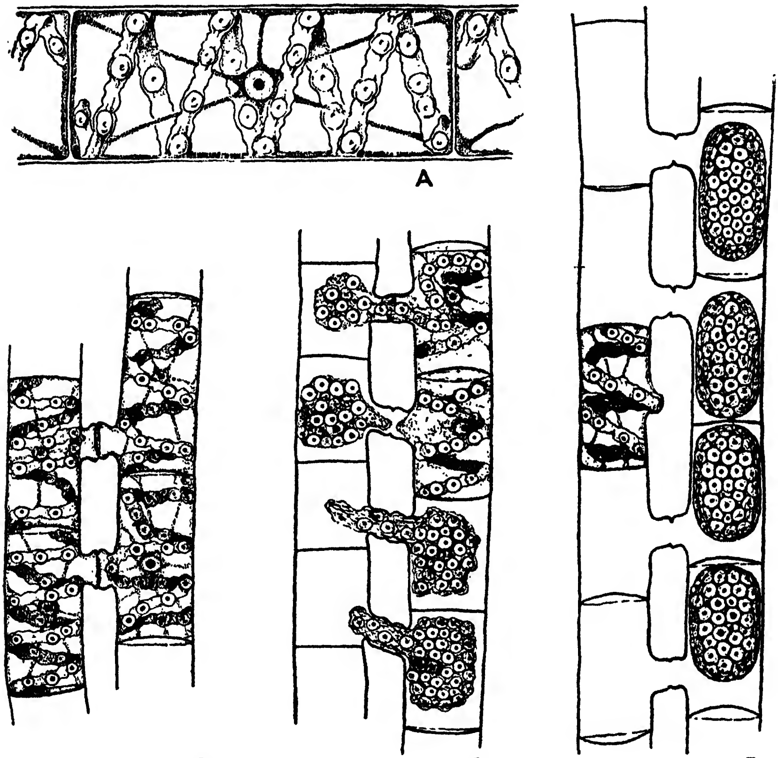


Fig. 21.—*Spirogyra*, a common green alga. *A*, a vegetative cell showing a central nucleus and a spiral ribbon-like chloroplast with many starch-forming bodies (pyrenoids), × 500; *B*, *C*, *D*, stages in sexual reproduction, × 250.

In some algae two filaments, lying parallel to each other, put out lateral projections that come in contact, forming tubes from one filament to the other (Fig. 21). Through these tubes the cell contents of the one filament pass to fuse with those of the other, forming heavy-walled zygotes. Here each vegetative cell gives rise to a single large gamete, which may be active or passive, but does not become ciliated or escape into the water. This

peculiar method of sexual reproduction is mentioned because it takes place in *Spirogyra,* one of the commonest of fresh-water algae and a form widely studied in elementary courses, although it is not a typical alga in many respects.

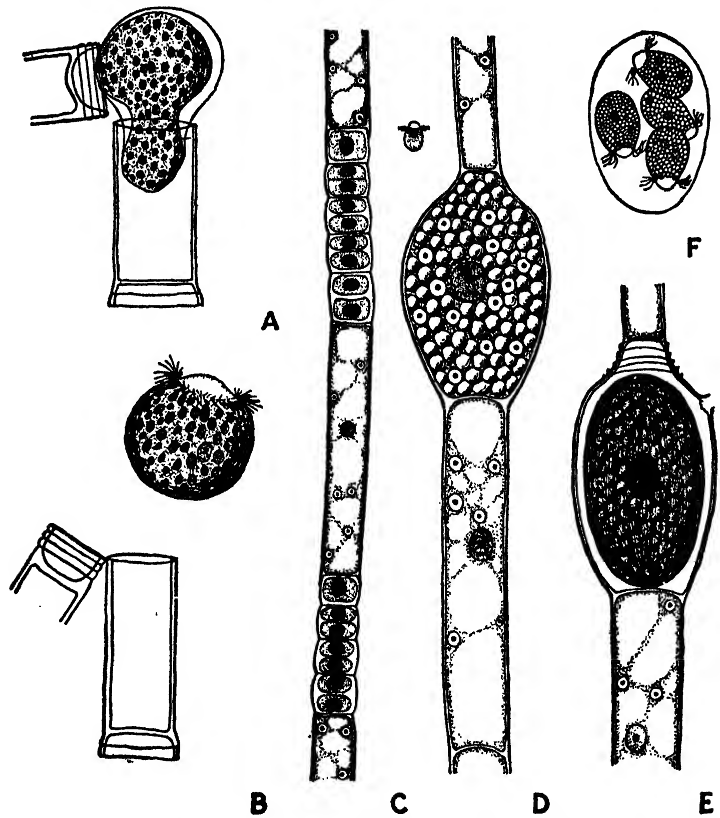


FIG. 22.—Reproduction in *Oedogonium,* a green alga, × 500. *A* and *B,* the entire contents of a vegetative cell escaping as a single swimming spore; *C,* male filament with two groups of sperm-producing cells separated by a vegetative cell; also a single escaped sperm; *D,* female filament with a large egg-producing cell and a vegetative cell; the egg contains a nucleus, starch-forming bodies (pyrenoids), and numerous starch grains; *E,* a heavy-walled zygote resulting from the fusion of sperm and egg; *F,* group of four swimming spores produced by the zygote. (*A and B, after Hirn; F, after Juranyi.*)

In only a relatively few algae are both of the fusing gametes alike in size and behavior. In most plants gametes are of two different kinds. The one remains small and active, while the other becomes large and passive, nearly always being retained

within the cell from which it arises (Fig. 22*C* and *D*). The smaller gametes, called *sperms* or male gametes, are ciliated and escape into the water. The larger one is known as the *egg* or female gamete. The large size of the egg is due to the accumulation of reserve food in the cytoplasm, its motility being sacrificed for an increased nutritive capacity. The sperm swims to the egg and fuses with it, this act being called *fertilization.* The zygote resulting from the union of a sperm and an egg is often called the *fertilized egg.*

The gametes of the lower algae, whether differentiated into sperms and eggs or not, arise directly from ordinary vegetative cells just as the spores do. In many of the algae, however, gametes are produced in special cells known as *gametangia* or sexual organs (Fig. 20*B*). Like sporangia, these are formed especially for the production of reproductive cells.

Groups of Algae.—All the algae contain chlorophyll, but, except in one group, some other pigment is present that more or less obscures the green color, and it is chiefly on this basis that the algae are classified. The four groups of algae, with their distinguishing characters, are given below.

1. *Blue-green Algae.*—These are the lowest of the algae, living in both fresh and salt water and on moist soil. Their color is due to the presence of a blue pigment in addition to the chlorophyll. They are all unicellular plants, and the cells may be either solitary or grouped to form colonies (Fig. 16*C* and *D*). Reproduction occurs exclusively by fission. In cell structure this group is the most primitive of all green plants. Chloroplasts are not present, the pigments being merely diffused throughout the cytoplasm. In the central part of the cell is a very primitive nucleus consisting only of a mass of chromatin granules not surrounded by a nuclear membrane.

2. *Green Algae.*—The green algae are predominantly fresh-water forms in which chlorophyll is the only pigment present. Most of them are multicellular, but unicellular forms occur and may be either solitary or colonial (Figs. 5, 16*A* and *B*, 18, 19, 21, and 22). Reproduction may occur by fission, by spores, or by gametes. As in all the higher algae, the cells contain a definite nucleus and one or more distinct chloroplasts.

3. *Brown Algae.*—These algae are almost all marine in distribution, occurring along nearly all seacoasts but reaching their

greatest development in cooler waters. Their cells contain a brown pigment in addition to the chlorophyll. None of the

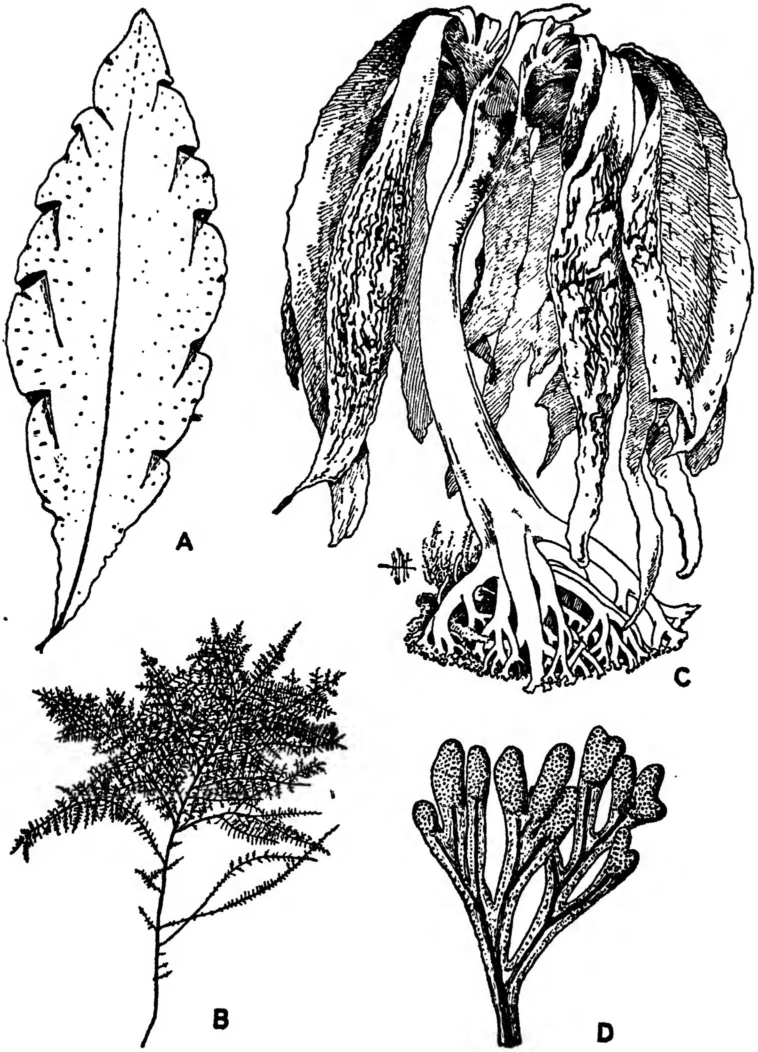


FIG. 23.—Some common seaweeds. *A*, a plate-like red alga (*Grinnellia*), × ½; *B*, a delicately branching red alga (*Gelidium*), × ½; *C*, a small kelp (*Eisenia*), × ½; *D*, a rockweed (*Hesperophycus*), × ¾.

brown algae are unicellular, and the multicellular body may be filamentous, plate-like, or may reach massive proportions and

become differentiated in form (Figs. 20, 23*C* and *D*). Some of the kelps growing along our Pacific Coast reach a length of 100 to 150 feet. Reproduction occurs by means of both spores and gametes.

4. *Red Algae.*—Like the brown algae, the red algae are almost exclusively marine but as a rule live in deeper and warmer waters than do the browns. In addition to chlorophyll, a red

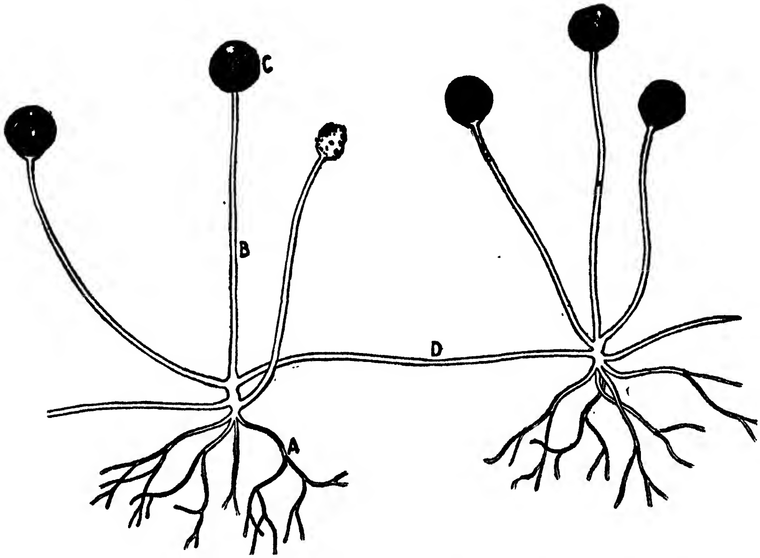


Fig. 24.—Mycelium of bread mold (*Rhizopus*) giving rise to sporangia. *A*, haustorium; *B*, sporangiophore; *C*, sporangium; *D*, horizontal branch. (*From Sinnott, "Botany, Principles and Problems."*)

pigment is present in the cells. No unicellular forms are known, and the multicellular bodies are not large but very diverse in shape, being filamentous, ribbon-like, or forming plates (Fig. 23*A* and *B*). The filamentous red algae are highly branched and very delicate. In fact, it is in this group that the filamentous type of plant body reaches its greatest development. Reproduction takes place by spores and gametes, sexual reproduction being very complex.

Fungi

Fungi are dependent thallophytes. All of them lack chlorophyll and live either on dead organic matter as saprophytes,

or on living organisms as parasites. Familiar kinds of fungi are bacteria, yeasts, molds, mildews, blights, smuts, rusts, and mushrooms.

Vegetative Body.—The bacteria and yeasts are unicellular forms, but practically all other fungi have a thread-like, branching body called a *mycelium*. For example, in *Rhizopus*, the common white mold that grows on moist stale bread, the mycelium consists of a fluffy mass of delicate threads that send short root-like branches (*haustoria*) into the bread and through which

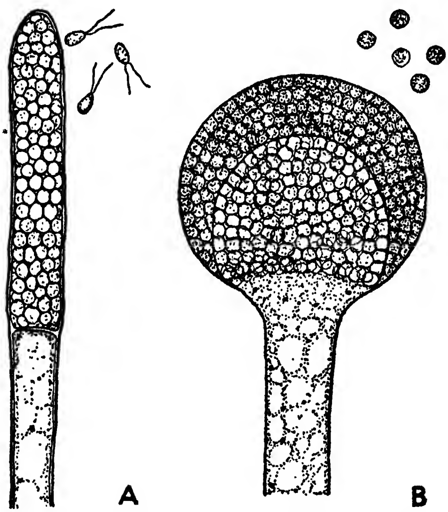


FIG. 25.—Spore production in two common fungi. *A*, sporangium of a water mold (*Saprolegnia*) with swimming spores; *B*, sporangium of bread mold (*Rhizopus*) with aerial spores.

food is absorbed (Fig. 24). In parasitic fungi the mycelium may grow on or beneath the surface of the organism attacked, but in either case the fungus absorbs nourishment directly from living cells (Fig, 26). In the group of fungi to which the bread mold belongs, the mycelium does not have cross walls dividing it up into individual cells, but in most fungi cross walls are present.

Reproduction.—The bacteria and other unicellular fungi reproduce by fission. In some of the lower fungi having a mycelium, such as the water molds—aquatic forms that live on dead fishes and insects—swimming spores are produced, but in the majority of fungi the spores are aerial (Fig. 25). Aerial spores differ from swimming spores in lacking cilia and in having

a cell wall. In practically all fungi the spores are borne in sporangia or in similar structures. In many of the higher forms

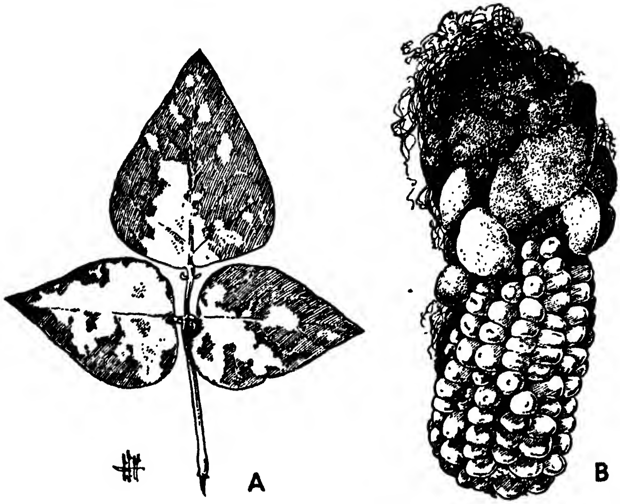


FIG. 26.—Two parasitic fungi. *A*, a mildew (*Erysiphe*) growing on a bean leaf × ½; *B*, a smut (*Ustilago*) attacking an ear of corn, some of the grains of which are greatly enlarged and filled with black spores, × ½. The mildew is an external parasite, the smut an internal one, but in both cases the mycelium absorbs nourishment directly from living cells.

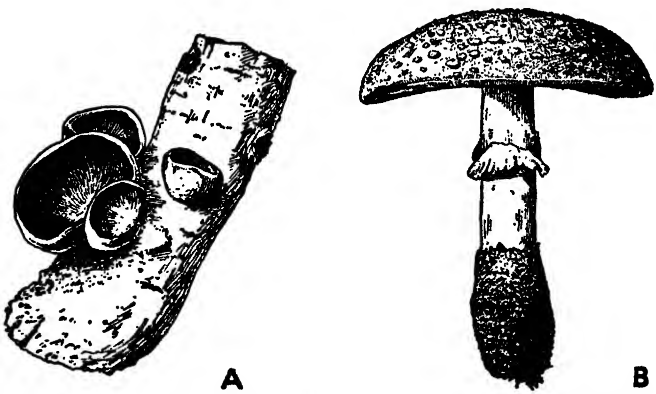


FIG. 27.—Two saprophytic fungi. *A*, a cup fungus (*Peziza*) growing on rotting wood, × ½; *B*, a mushroom (*Amanita*) that lives in soil, × ⅓. In both cases these fleshy bodies arise from a colorless mycelium living in the decaying organic matter, and produce innumerable aerial spores.

the mycelium gives rise to conspicuous fleshy bodies that produce innumerable aerial spores (Fig. 27). Sexual reproduction among

many of the fungi is an obscure process and is frequently not present.

BRYOPHYTES

The second great plant group, comprising the *liverworts* and *mosses*, numbers about 16,000 species. Bryophytes are small,

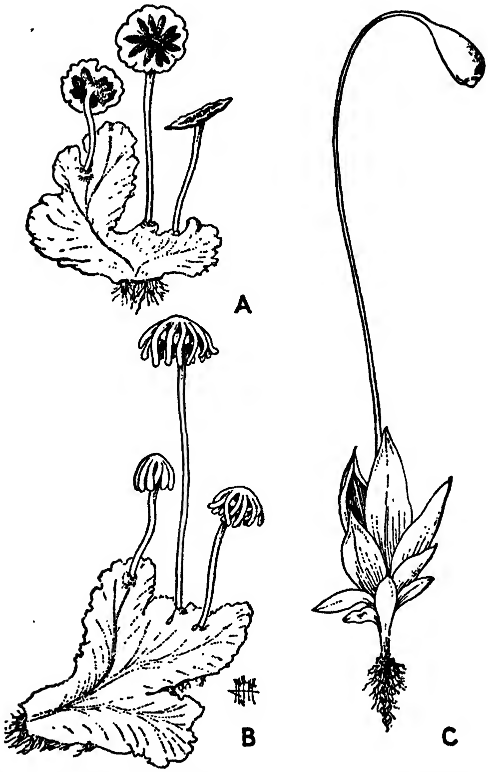


FIG. 28.—Two common bryophytes. *A* and *B*, male and female plants, respectively, of a liverwort (*Marchantia*), × 1. The gametophyte consists of a flat thallus with upright branches bearing sexual organs. *C*, a moss (*Funaria*), × 2. The long-stalked sporophyte is attached to the upper end of the leafy gametophyte.

rather inconspicuous, green plants that live mostly on moist soil, rocks, tree trunks, and in similar situations. They are of considerable scientific interest in that they are a transitional group, being closely related on the one hand to the green algae and on the other hand to the higher plants. It is noteworthy that the simplest plants (the algae) are aquatic, while the bryophytes, but

slightly more advanced structurally, grow on land but mostly in wet places close to the ground.

Vegetative Body.—Some of the liverworts have a vegetative body consisting of a flat, plate-like or ribbon-like thallus (Fig. 28*A* and *B*). This may consist of only a few layers of simple cells or may be thicker and show some internal differentiation. In most of the liverworts and in all of the mosses, the vegetative body is not a flat thallus but is made up of simple stems and leaves (Fig. 28*C*). It is apparent that an erect leafy shoot permits of a greater exposure of green tissue to the light than does a flat thallus and thus favors photosynthesis. The stems and leaves of bryophytes are much simpler than those of the higher plants, and in none of the bryophytes are roots present. The vegetative body, whether thalloid or leafy, sends into the soil numerous slender, filamentous hairs called *rhizoids*, which are both anchoring and absorptive in function. The stem, made up largely of simple uniform cells, contains no woody tissue, while the cells of the leaf generally form a single layer.

Sexual Organs.—In the bryophytes, gametes are borne in complex sexual organs that arise on the vegetative body described above. The sexual organs of thallophytes, where present, are mostly unicellular and simple, but those of all bryophytes are multicellular and complex, exhibiting a characteristic structure. The male organs of bryophytes are called *antheridia*, the female organs *archegonia*. In some of the liverworts the sexual organs are borne on special upright branches of the thallus (Fig. 28*A* and *B*), while in the mosses they arise in clusters at the apex of the stem (Fig. 29*A*). In some mosses both kinds of sexual organs are present in the same cluster; in others, they occur on separate plants.

The antheridia are stalked, ellipsoidal organs consisting of a layer of sterile cells surrounding a large number of small sperm-producing cells (Fig. 29*B*). The sperms are minute curved cells bearing a pair of long cilia (Fig. 29*C*). The archegonia are flask-shaped organs, each having a slender neck and a lower bulbous portion consisting of one or more layers of sterile cells enclosing a large non-motile egg (Fig. 29*D*). When mature, the neck of the archegonium opens, forming a passageway to the egg. In the presence of moisture the antheridia break open to liberate the sperms. The latter swim toward the archegonia and enter

the necks. Fertilization is effected when a single sperm penetrates the egg and fuses with it to form a zygote.

Because the green vegetative body produces sexual organs in which gametes arise, it is called a *gametophyte*. A different kind

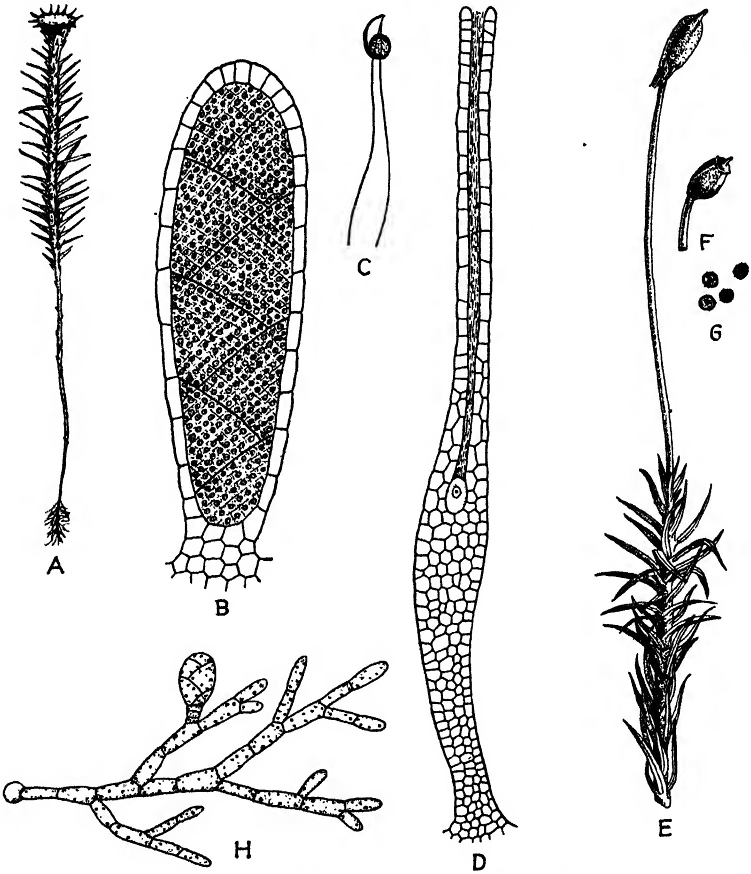


Fig. 29.—Life history of a moss (mainly *Polytrichum*). *A*, male plant bearing a cluster of antheridia at its upper end, × 1; *B*, longitudinal section of an antheridium, × 150; *C*, enlarged view of a sperm; *D*, longitudinal section of an archegonium, × 150; *E*, female plant with a mature sporophyte arising from its upper end, × 1; *F*, a capsule from which the outer covering has been removed; *G*, enlarged view of several spores; *H*, a protonema bearing a bud from which an erect leafy shoot will arise, × 75.

of individual is involved in the life history of the bryophytes, however, *viz.*, a *sporophyte*. The latter comes from the zygote and in turn produces spores.

Sporophyte.—The zygote does not escape and pass into a resting condition, as in most of the algae, but develops at once inside the archegonium where it was formed. By repeated cell division, the zygote gives rise to a mass of undifferentiated cells constituting the *embryo.* As it develops, the cavity of the archegonium enlarges. The embryo continues to grow, obtaining its nourishment directly from the gametophyte, and in nearly all bryophytes finally becomes differentiated into three regions: a lower *foot,* a middle stalk or *seta,* and an upper spore-bearing *capsule* (Figs. 28*C* and 29*E*). The foot is an absorbing and

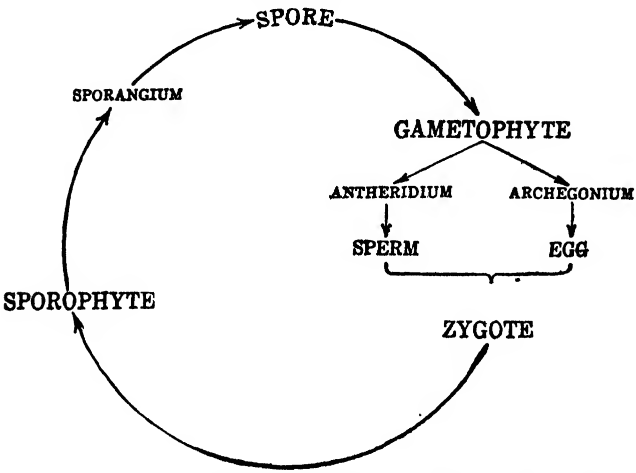


FIG. 30.—Diagram illustrating the general scheme of alternation of generations in a moss or a fern.

anchoring organ. The seta often becomes long, carrying the capsule up into the air. Within the capsule are formed numerous spores that when ripe are disseminated by the air. The capsule is really a sporangium but is multicellular and often highly specialized, being very different from the simple sporangia found among the algae. When the spore of a liverwort germinates, it gives rise directly to the green vegetative body that later produces the sexual organs. In the mosses, however, the spore produces a green, branching filament called the *protonema* (Fig. 29*H*). Upon this buds appear, each of which may then give rise to an erect leafy shoot that later bears the sexual organs.

Alternation of Generations.—The life history of a liverwort or a moss introduces the phenomenon of *alternation of generations.*

Briefly stated, this means that two kinds of individuals alternate in every life cycle, one producing spores (*sporophyte*) and the other gametes (*gametophyte*). Figure 30 represents the general scheme of alternation of generations. The sporophyte represents the asexual generation, the gametophyte the sexual one. The former always arises from the zygote, the latter from a spore.

An important feature of the bryophytes is the fact that the gametophyte is always an independent plant, but the sporophyte

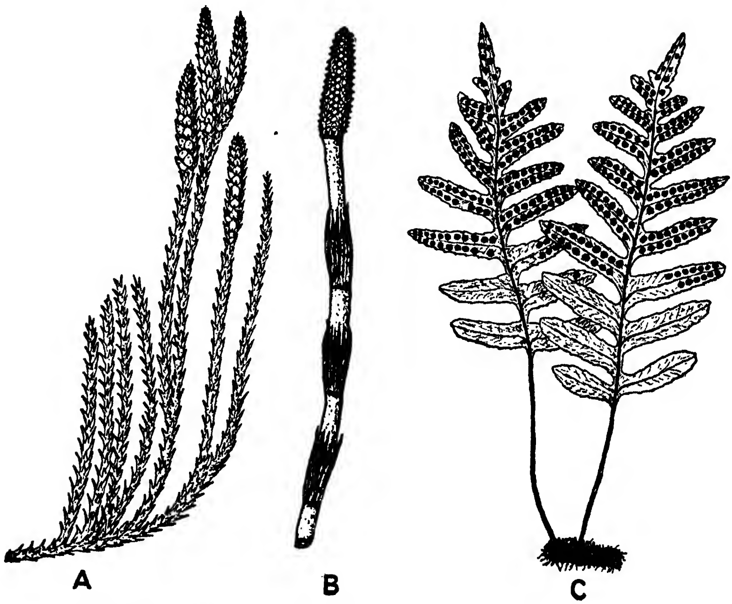


FIG. 31.—Representative pteridophytes. *A*, a lycopod (*Lycopodium*), × ¾; *B*, a horsetail (*Equisetum*), × ½; *C*, a fern (*Polypodium*), × ½. In *A* and *B* the leaves are small and the sporangia borne in terminal cones, while in *C* the leaves are large and divided, and the sporangia borne in localizing groups on their lower surface.

is not because it derives all or most of its nourishment from the gametophyte. For this reason the gametophyte is relatively conspicuous. It should be kept in mind that the rhizoids, stems, and leaves of bryophytes belong to the gametophyte generation and have none of the complex structural features exhibited by the sporophytic roots, stems, and leaves of the two higher plant groups.

A definite alternation of generations is thoroughly established in all plants above the thallophyte level, but notable changes

occur in the relative importance of the gametophyte and sporophyte in the life history, as will be seen later. Alternation of generations occurs in many of the thallophytes, but frequently is not well defined, the gametophyte and sporophyte being independent of each other and often similar in appearance.

PTERIDOPHYTES

The ferns and their relatives constitute a comparatively small group of plants today, being represented by only about 5,000

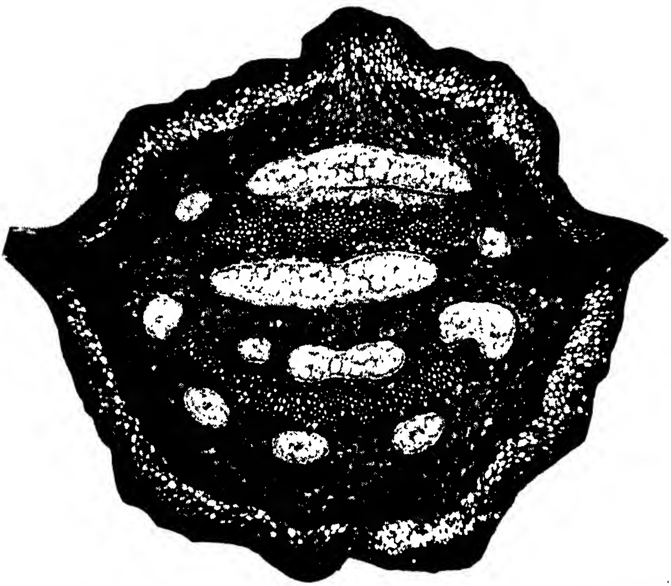


Fig. 32.—Photomicrograph of a cross section of a fern stem (*Pteris aquilina*), × 16. The vascular system is composed of numerous strands, each consisting of xylem surrounded by phloem.

species, but in past geologic times they were much more numerous. There are three modern groups of pteridophytes: the *lycopods* (often inappropriately called "club mosses"), the *equisetums* or "horsetails," and the *ferns*. By far the largest group is the ferns.

Vegetative Body.—An ordinary fern plant consists of an underground stem (*rhizome*) that sends out roots into the soil and leaves into the air. Fern leaves are typically large and divided into many small leaflets, but in the lycopods and horsetails the leaves are small, undivided, and closely crowded on the

stem (Fig. 31). The stems and leaves of pteridophytes are much more complex structurally than those of bryophytes, while roots, which are entirely absent in the two lower plant groups, are present in practically all pteridophytes.

A cross section of a fern stem reveals the presence of a well-developed *vascular* or *conducting* system (Fig. 32). This is continuous throughout the plant body, beginning in the roots and extending into the leaves. A vascular system is not present in the thallophytes and bryophytes, but is characteristic of all the higher plants. It consists mainly of two kinds of tissues: *xylem* and *phloem*. Xylem (wood), when mature, is made up largely of greatly elongated cells with thick cell walls but no protoplasmic contents. It gives strength to the plant, permitting it to grow up into the air, and also conducts water from the roots to the leaves. Phloem consists of elongated cells with thin cell walls and with protoplasm. Its function is to transport food from the leaves to other parts of the plant.

Spore Production.—The vegetative body described above is a sporophyte because it produces spores. In all pteridophytes these are borne in complex sporangia. The sporangia of ferns commonly arise on the underside of the ordinary leaves in small groups called *sori* (Fig. 33). A sorus is usually covered by a membrane known as the *indusium*, but in some ferns no indusium is present. Each sporangium is a stalked organ consisting of a layer of sterile cells enclosing a number of thick-walled aerial spores. A ring of thick-walled cells, constituting the *annulus*, extends vertically about two-thirds of the way around the sporangium; it is concerned with the discharge of the spores. In the lycopods and horsetails the sporangia are borne in terminal *cones* (Fig. 31*A* and *B*).

Gametophyte.—When a fern spore falls upon moist earth, it produces a flat, green, heart-shaped thallus that reaches a diameter of about ¼ inch and closely resembles a simple liverwort (Fig. 34). From its lower surface numerous rhizoids are put out into the soil. Sexual organs are also borne on the lower side, the antheridia being scattered among the rhizoids, the archegonia occurring near the notch. Both kinds of sexual organs are simpler in the ferns than in the mosses but have the same general structure (Fig. 35). The sperms, which are relatively large, coiled, and multiciliate, are discharged from the antheridia and

swim toward the archegonia. Since the thallus is in contact with moist earth, fertilization presents no difficulties. The sperm

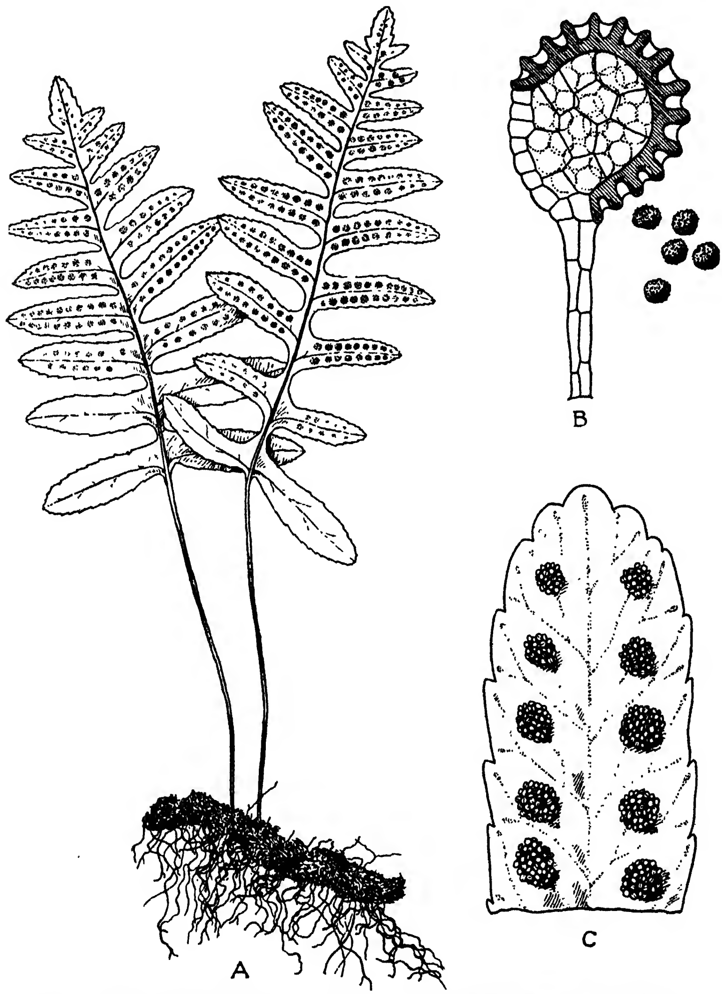


FIG. 33.—Spore-bearing structures of a fern (*Polypodium californicum*). *A*, the sporophyte, consisting of a rhizome bearing roots and large divided leaves, $\times \frac{2}{3}$; *B*, portion of the underside of a leaflet showing the sori, $\times$ 4; *C*, a single sporangium with its annulus and several spores, $\times$ 150. In this fern the sori are not covered by an indusium.

enters the archegonium and fuses with the egg, and the zygote germinates at once. As in the mosses, the zygote does not escape but produces an embryo that develops for a while inside

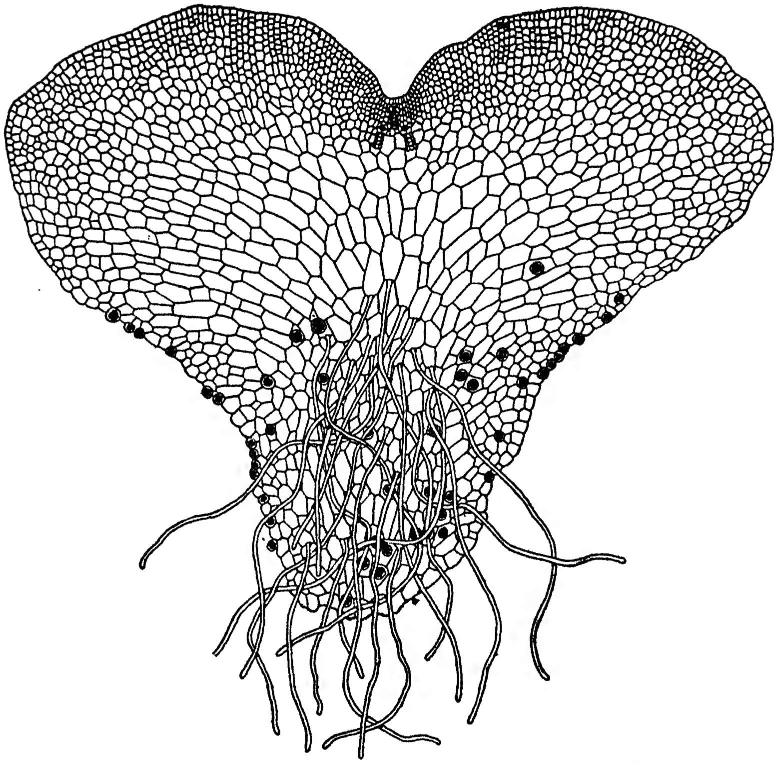


Fig. 34.—View of the lower surface of a fern gametophyte, showing rhizoids and numerous antheridia, and three archegonia near the notch, × 35.

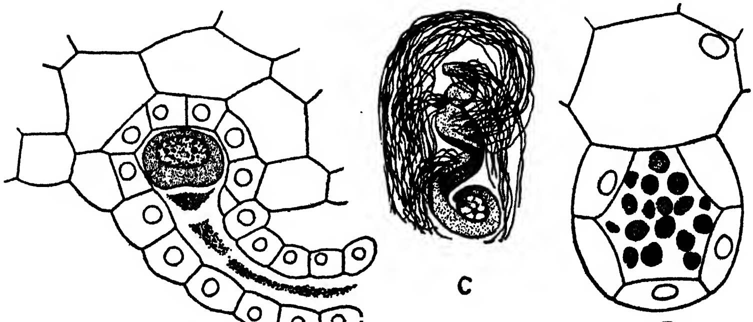


Fig. 35.—Sexual organs of a fern. *A*, longitudinal section of an archegonium containing a single large egg, × 350; *B*, longitudinal section of an antheridium containing a number of sperms, × 500; *C*, a single sperm, more highly magnified. (*C*, *after Yamanouchi.*)

the archegonium. The embryo grows rapidly, soon forming a stem, root, and leaf. The young sporophyte remains attached to the gametophyte for a while, absorbing nourishment from it, but soon becomes an independent plant (Fig. 36). Then the gametophyte dies. In the lycopods and horsetails the spores similarly produce small gametophytes that bear sexual organs of the same general type as those of ferns. Likewise the development of the embryo and its relation to the gametophyte are essentially similar to the condition in ferns.

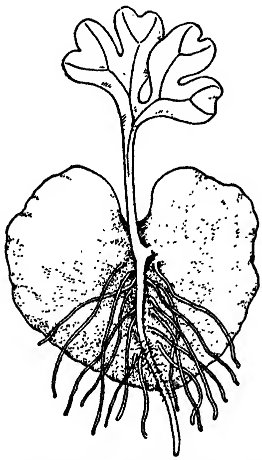


FIG. 36.—Young fern sporophyte attached to the gametophyte, × 5.

It is apparent that the conspicuous difference between a moss and a fern is the presence of an independent leafy sporophyte in the latter. In the bryophytes the gametophyte carries on all or nearly all the work of photosynthesis, the sporophyte, in all cases, being leafless and entirely or largely dependent upon it for nourishment. In the pteridophytes, on the other hand, by developing highly differentiated vegetative organs, the sporophyte attains independence and becomes the dominant generation. The fern gametophyte is consequently a greatly reduced structure concerned with the production of gametes and not primarily with the manufacture of food, the latter being mainly a function of the sporophyte.

Heterospory.—In most of the pteridophytes the spores are small and all alike, but in some cases two kinds of spores are present. The former condition is known as *homospory*, the latter

as *heterospory*. Thus in *Selaginella*, one of the lycopods, the cone produces two kinds of sporangia, one kind containing many small *microspores*, the other giving rise to four large *megaspores* (Fig. 37). As in other pteridophytes, the spores are shed from their sporangia and fall to the ground. The microspores produce *male gametophytes* bearing only antheridia; the megaspores,

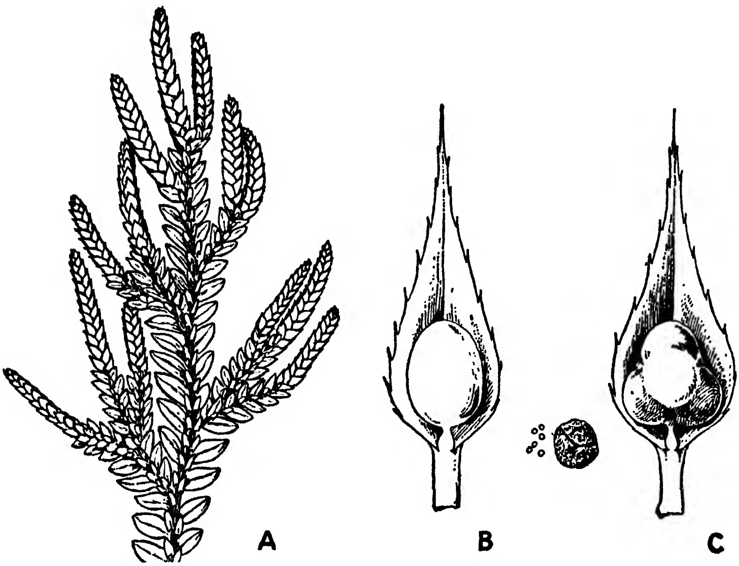


FIG. 37.—*Selaginella*, a heterosporous pteridophyte. *A*, portion of sporophyte of *Selaginella willdenovii*, showing terminal cones, × 2; *B*, cone scale bearing a microsporangium containing many small spores, × 25; *C*, cone scale bearing a megasporangium containing four large spores, × 25; several microspores and a megaspore drawn to the same scale are also shown.

female gametophytes bearing only archegonia. Both kinds of gametophytes are greatly reduced, developing within the spore coat and remaining colorless. Thus heterospory introduces into the life history not only two kinds of spores but also two kinds of gametophytes, which are sexually differentiated, and a great reduction in the gametophyte generation.

CHAPTER V

VEGETATIVE ORGANS OF SEED PLANTS

The spermatophytes constitute the fourth and highest division of the plant kingdom. Their name means "seed plants," and is appropriate because they are the only plants that bear seeds. Like the pteridophytes they have an independent sporophyte with a woody conducting system and are also highly specialized in regard to the structure of their vegetative organs. The spermatophytes not only surpass the other groups in structural complexity, but are the most numerous, there being about 150,000 species.

There are two subordinate groups of spermatophytes: the *gymnosperms* and the *angiosperms*. The former, numbering only about 500 living species, are an ancient group with a long geologic history. Like the pteridophytes, they were more numerous during past ages than they are now. Gymnosperms are represented today chiefly by the *cycads* and the *conifers*, nearly all of which are trees. The cycads are tropical plants with large fern-like leaves, while the conifers, with small needle-like or scale-like leaves, include the familiar pines, firs, spruces, hemlocks, cedars, redwoods, etc. The seeds of gymnosperms are borne in a woody cone composed of scales (Fig. 38*A*). The name gymnosperm means "naked seed," in reference to the fact that their seeds are borne freely exposed on the face of the cone scales (Fig. 67*A*).

Historically, angiosperms are a younger group than gymnosperms and are much more numerous today. In fact, angiosperms are the dominant group of modern plants. They are often referred to as "flowering plants," as the presence of flowers is one of their outstanding features (Fig. 38*B*). The name angiosperm means "enclosed seed," signifying that the seeds are produced in a closed vessel (*ovary*) that ripens to form a fruit (Fig. 67*B*). Nearly all the common plants of everyday experience are angiosperms.

In dealing with the seed plants, we shall consider first their vegetative organs, reserving a discussion of their reproductive features for the next chapter. As in pteridophytes, the vegetative body is made up of three distinct kinds of organs: roots, stems, and leaves, all of which are highly differentiated structurally. They are called *vegetative organs* because their chief

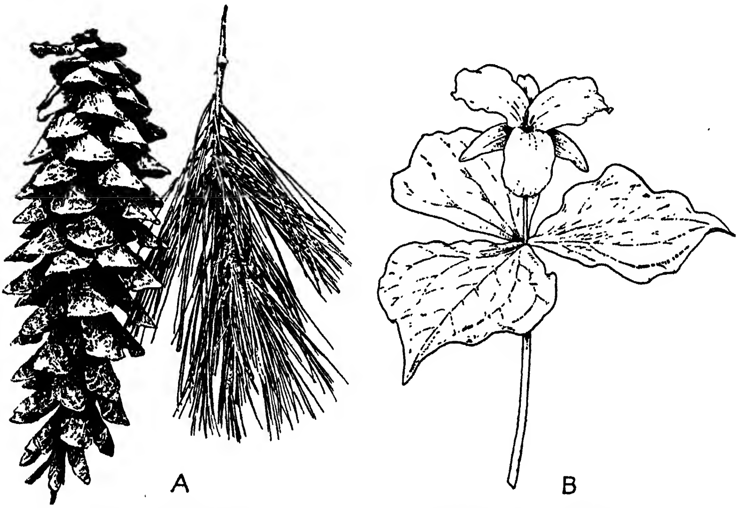


Fig. 38.—Spermatophytes. *A*, mature seed-bearing cone and leafy branch of white pine (*Pinus strobus*), a gymnosperm, × ½; *B*, white trillium (*Trillium grandiflorum*), an angiosperm, × ⅓. In the pine two "naked" seeds are borne at the base of each cone scale. In the trillium many "enclosed" seeds are borne within a fruit which develops from one of the floral organs.

functions are concerned with the nutrition of the plant body, providing for its growth and continued existence.

THE ROOT

The roots of a plant, collectively constituting its *root system*, place it in intimate relations with the soil. The welfare of the plant demands that these be maintained at all times. The root system performs two primary functions: *anchorage* and *absorption*. When a plant is uprooted, it soon wilts and eventually dies, primarily because its source of water has been cut off. The plant obtains its entire water supply through its roots. It also absorbs from the soil other substances necessary to its welfare, especially dissolved mineral salts.

Organization of Root Systems.—Some root systems consist of one main root, called the *taproot*, which grows straight downward into the soil, giving rise to many smaller branches. In other plants one large root does not dominate the others, but the root system consists of a cluster of highly branched *fibrous roots*, all of which are slender and equally prominent. Between these two extremes, however, are many root systems of intermediate character, and so these "types" have no great significance. The important point is that the larger roots give rise to smaller and smaller branches, which penetrate the soil in all directions. It should be noted that there is no regularity to the way in which branch roots arise, the smaller ones springing from the larger ones without much predetermined order. Another fact of importance is that the tips of all roots are constantly elongating, pushing their way out into the soil. Furthermore, it is only these delicate rootlets which carry on the work of absorption, and so, as a root system grows, its absorbing region moves farther and farther out into the soil.

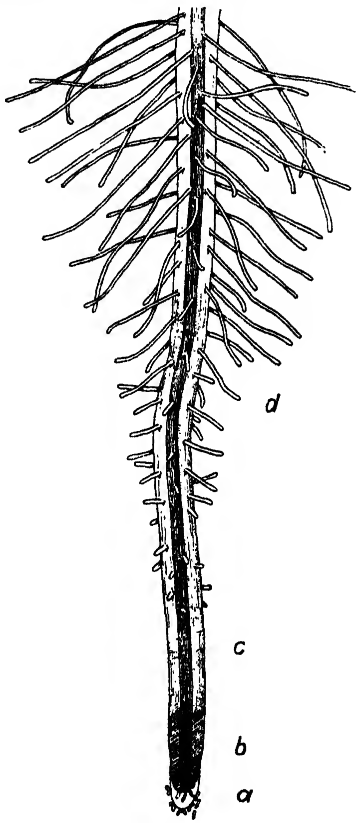


FIG. 39.—Root tip of a grass seedling grown in water, × 35; *a*, rootcap; *b*, embryonic region; *c*, region of elongation; *d*, region of maturation.

Structure of Root Tip.—The structure of a root tip can be studied to good advantage by examining with a microscope the young rootlets put out by sprouting seeds (Fig. 39). Fitting over the end of the root tip is a thimble-shaped group of cells forming the *rootcap*, a structure that serves as a buffer to the rootlet as it pushes through the soil, protecting the delicate cells that lie immediately behind. Just back of the rootcap is the *embryonic region*, of

very limited extent, consisting of a small group of undifferentiated cells constantly undergoing division. Each of the embryonic cells is more or less cubical, with a thin wall, dense cytoplasm, and a relatively large nucleus (Fig. 3*A*). The embryonic region gradually merges into the *region of elongation*, about ⅛ inch in extent, where the newly formed cells increase in size, especially in length. The cells in this region have slightly thicker walls, and, because of the development of

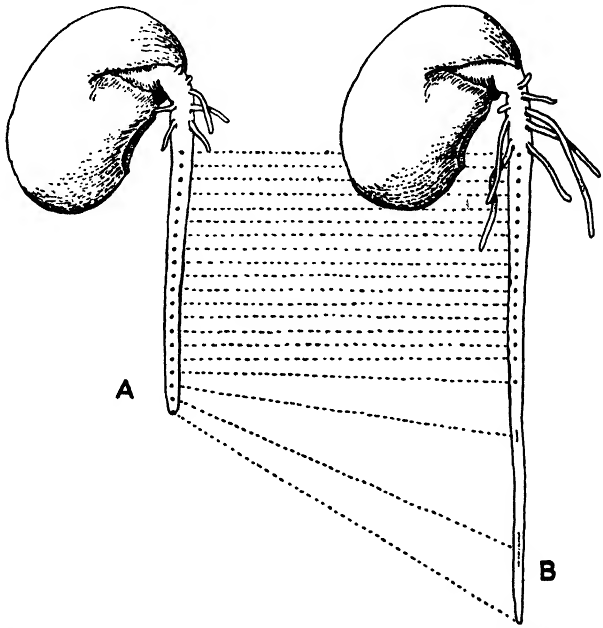


FIG. 40.—Growth of the root in length, natural size. *A*, seedling of scarlet runner bean with equidistant dots placed along the primary root; *B*, the same seedling 24 hours later, showing elongation only near the tip.

large vacuoles, the cytoplasm no longer appears dense (Fig. 3*B* and *C*). The fact that elongation is restricted to this region may readily be demonstrated by placing a row of equidistant dots along the entire length of a young root and a day or two later observing which ones have moved apart (Fig. 40).

Behind the region of elongation is the more extensive *region of maturation*, easily recognized externally by the presence of numerous *root hairs*, which are slender outgrowths from the outermost layer of cells (*epidermis*). It is here that the cells of the

root become differentiated in structure and specialized in function, assuming their mature characteristics. In addition to root-hair formation, the most conspicuous change seen in this region

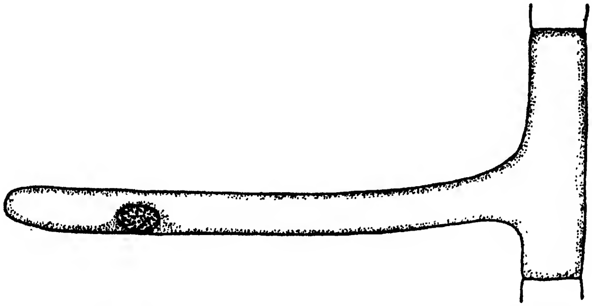


FIG. 41.—Enlarged view of one of the root hairs shown in Fig. 39, × 350.

is the development of strands of elongated conducting cells in the center of the root. Root hairs are epidermal outgrowths, each one representing a single cell (Fig. 41). They have a thin wall and a lining of cytoplasm around a large central vacuole. Their presence very effectively increases the absorbing surface of the rootlet. When roots are grown in soil, the root hairs become firmly united with the soil particles (Fig. 42). Since the latter are surrounded by films of water, the intimate contact of root hairs to soil particles enables a maximum quantity of available moisture to be absorbed.

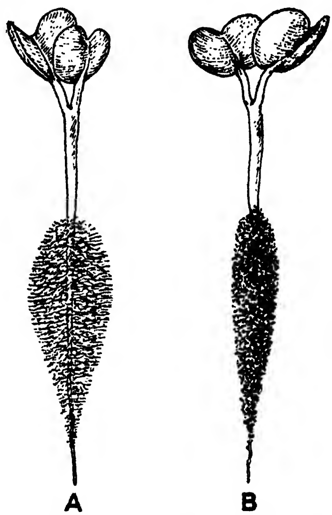


FIG. 42.—Radish seedlings grown in moist air (*A*) and in soil (*B*), showing root hairs, natural size.

Structure of Mature Root.—The root-hair zone extends back only a short distance and gradually merges into the mature root. The differentiation of tissues, begun in the younger part of the root, has now become complete. A cross section of a root, taken behind the root-hair zone, shows two distinct regions: an outer *cortex* and a central *vascular cylinder* (Fig. 43). The cortex consists of rather large, thin-walled, relatively undifferentiated cells forming a

kind of tissue known as *parenchyma.* Frequently, as here, parenchyma is a rather loose tissue, characterized by conspicuous intercellular spaces. The cortex is bounded externally by an *epidermis,* the layer from which, in the young root,

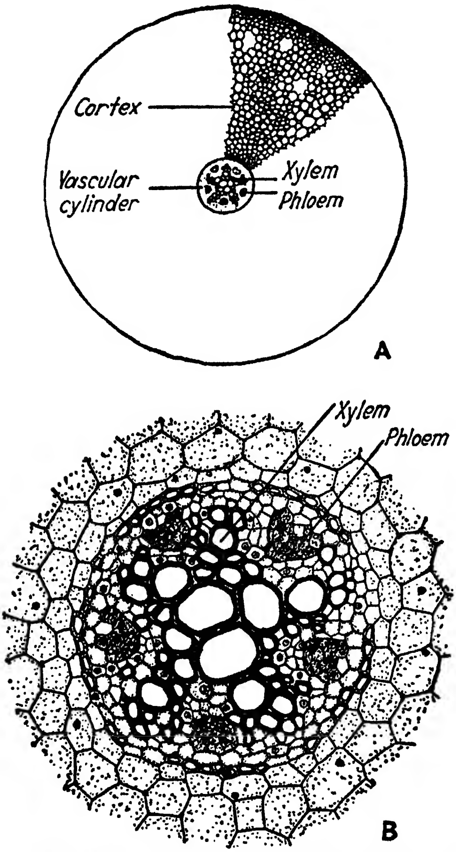


FIG. 43.—*A*, diagrammatic cross section of a buttercup root (*Ranunculus acris*), showing an outer cortex and a central vascular cylinder, × 30; *B*, enlarged view of the latter, showing the relation of xylem to phloem, × 150. The cortex is bounded externally by the epidermis, internally by the endodermis.

the root hairs arise. The epidermis is soon replaced by *cork,* a tissue consisting of layers of small, dead, cubical cells that form a tough protective covering.

The vascular cylinder of the mature root consists mainly of cells specialized for the conduction of fluids. As already noted,

two kinds of conducting tissues are present in the pteridophytes and spermatophytes, *viz.*, *xylem* and *phloem.* Both kinds of tissues are made up of elongated cells, but the cells of the xylem are thick walled and dead, while those of the phloem are thin walled and living. The xylem tissue in a root is arranged like the spokes of a wheel, usually forming a solid central strand, and between its rays are small isolated strands of phloem surrounded by more or less parenchyma (Fig. 43). Frequently the vascular cylinder is enclosed by a specialized layer of thick-walled cells constituting the *endodermis.*

Branch roots always originate in the outer part of the vascular cylinder and push their way outward through the cortex, a feature that can be clearly seen by splitting open a carrot root. This peculiarity is in marked contrast to the way in which branches arise on the stem. In plants that live from year to year, the roots increase in thickness through the activity of a special layer of cells called the *cambium,* situated between the xylem and phloem. Cambial activity will be discussed in connection with the stem.

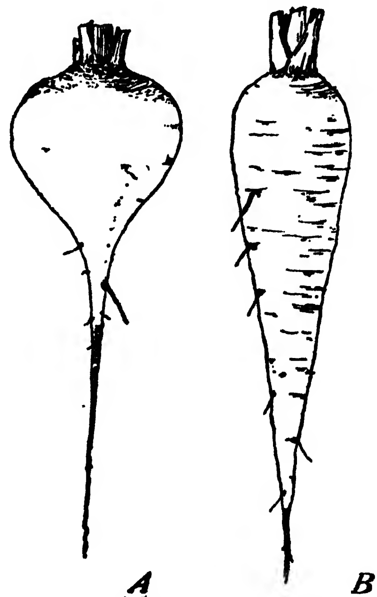


FIG. 44.—Storage roots of beet (*A*) and of carrot (*B*), × ½.

Food Storage in Roots.—Some plants that live through only one growing season, and many which live longer, accumulate food in their roots, and these become thick and fleshy as a result. Storage roots are seen in such common plants as the dandelion, radish, turnip, beet, carrot, and sweet potato (Fig. 44). Their food is mostly in the form of starch, but in some, sugar is frequently present as well. Storage roots also contain a large proportion of water—commonly 80 to 90 per cent. By the accumulation of large quantities of food and water in their roots during the growing season, some plants are able to make a vigorous growth above ground the following spring.

THE STEM

Stems are concerned chiefly with the bearing of leaves, and it is to this fact that they owe their distinctive features. The stem has two primary functions: *support* and *conduction.* It supports the leaves (as well as the flowers and fruits) and conducts sub-

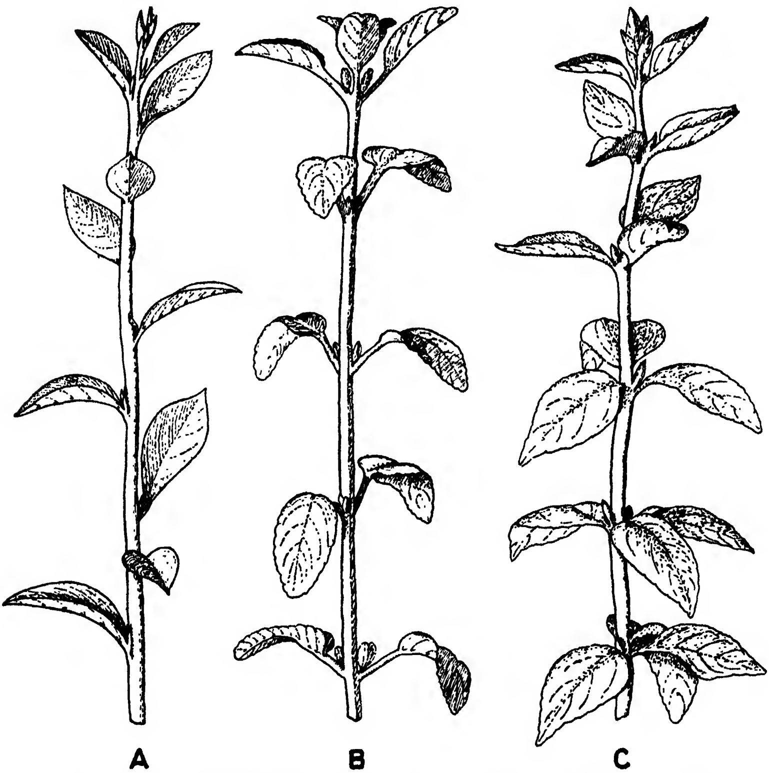


FIG. 45.—Three types of leaf arrangement, one-half natural size. *A*, alternate leaves of *Cotoneaster; B*, opposite leaves of *Salvia; C*, whorled leaves of *Abelia.* In each case one leaf does not stand directly over another so as to shade it. A bud is present in the axil of every leaf.

stances in solution to and from them. It is apparent that the stem connects the roots with the leaves both structurally and functionally. A leafy stem is called a *shoot,* while all of the stems and leaves of a plant constitute its *shoot system.* Just as the functions of the root system are related to the soil, so are those of the shoot system related to the air and light.

Arrangement of Leaves.—Leaves are not scattered over a stem promiscuously but are always borne according to a definite and symmetrical arrangement (Fig. 45). The place on the stem where a leaf is attached is called a *node*, while the regions between successive nodes are known as *internodes*. In most plants only one leaf is borne at a node, but commonly there are two, one standing opposite the other. The former constitutes an *alternate* arrangement, the latter an *opposite* one. In a comparatively few plants the leaves are *whorled*, there being three or more at a node. It is generally true that, regardless of the number of leaves at a node, leaves tend to be arranged on an erect shoot in such a regular manner that one leaf does not stand directly over another and thus shade it, for the chief work of leaves demands that they be freely exposed to the light.

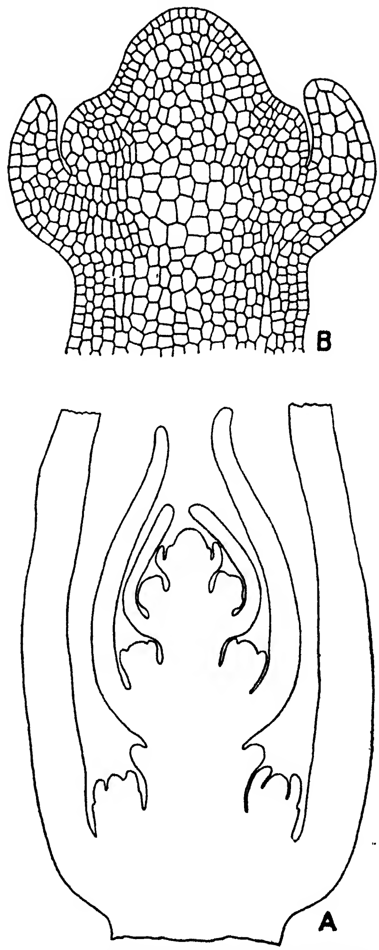


FIG. 46.—Stem tip of *Salvia grahami*. *A*, longitudinal section, showing the development of young leaves and lateral buds, × 35; *B*, enlarged view of upper portion of same, showing stem apex and two rudimentary leaves, × 175.

Buds and Branches.—The stems of most seed plants increase in length only at their tips, and it is only here that new leaves are formed. At the apex of the growing stem tip is a small cone-shaped mass of undifferentiated cells in an active state of cell division, immediately behind which there arise minute lateral outgrowths that develop into leaves, the youngest being nearest the stem apex (Fig. 46). While the leaves are still very small, secondary stem tips may arise in their

axils, as Fig. 46 clearly shows, or these may not appear until later. The *axil* is the upper angle formed where the leaf is attached to the stem.

The portion of the shoot just described constitutes a *bud*, which is thus merely an undeveloped or embryonic shoot—a

FIG. 47.—A young (*A*) and an older (*B*) shoot of *Cotoneaster*, showing the development of branches from lateral buds, one-half natural size. A terminal bud is present at the upper end of each shoot, and a lateral bud in the axil of each leaf.

structure having the capacity of becoming a mature leafy stem. A bud "opens" simply by the elongation of its internodes accompanied by the unfolding and enlargement of its leaves. The bud situated at the upper end of a main shoot is called the *terminal bud*, and by its activity the stem increases in length.

The secondary buds, arising in the leaf axils, develop into branch shoots and because of their position are called *lateral* or *axillary buds* (Fig. 47). The leaf in whose axil a bud is formed may fall off the stem before the branch shoot develops, or it may persist for a longer or shorter period.

In nearly all herbs and in many woody plants of warm regions, the cells at the apex of the stem tip may continue to divide and to produce new leaves during the entire growing season, growth of the shoot being here more or less a continuous process. In most of the woody plants of colder regions, however, resting buds form and growth is periodic. In such cases buds form during the growing season, remain dormant over the winter, and expand during the following spring. In nearly all such *winter buds*, as they are called, the lower leaf rudiments develop as scales that closely overlap and protect the delicate parts within, dropping off when the bud opens and leaving characteristic scars on the stem (Fig. 48). The protective function of bud scales is often augmented by the presence of hairs, wax, or a resinous varnish.

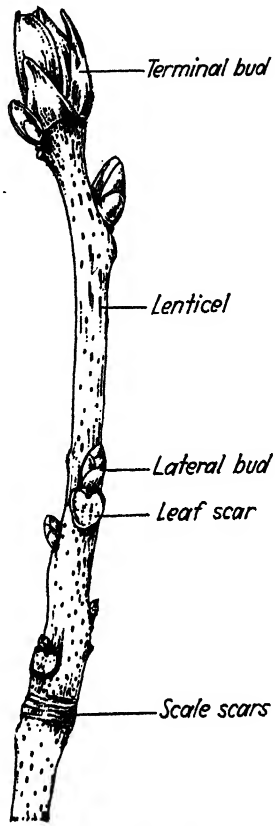


FIG. 48.—Twig of shagbark hickory (*Carya ovata*) in winter condition, natural size.

It is apparent from the preceding account that the chief external difference between stems and roots arises from the fact that stems bear leaves according to a regular arrangement, and that buds, which develop into branch shoots, appear in the leaf axils. Roots, on the other hand, branch indiscriminately and do not bear leaves.

Habit.—The general aspect of a plant, called its *habit*, is determined largely by such features of the shoot system as its growth direction, duration, and type of branching. Although the stems of most plants grow erect and support their own weight, those of

vines are too weak to do so. Some vines, such as cucumbers, creep or trail along the ground. Others have developed the climbing habit, either twining about a support, like a morning-

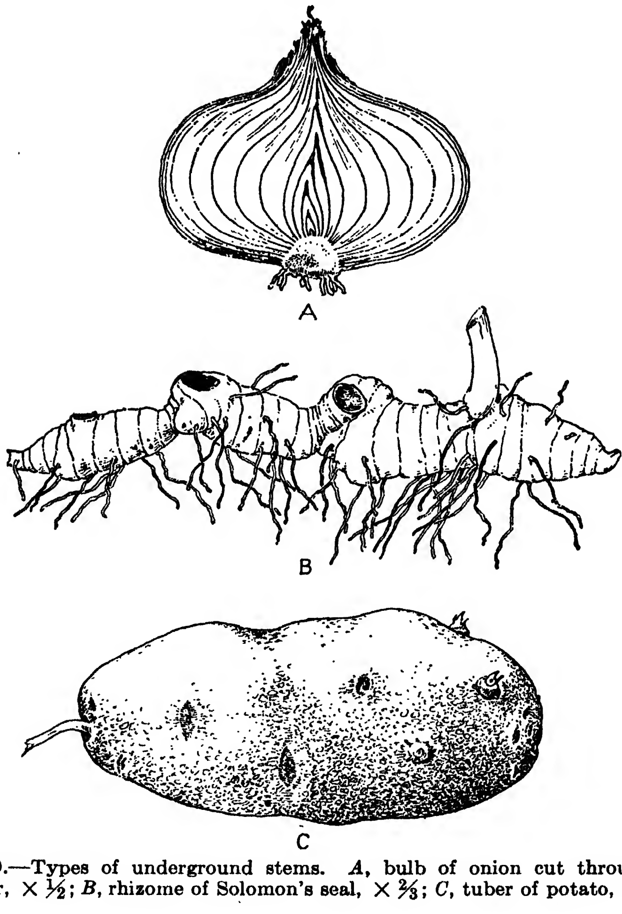


FIG. 49.—Types of underground stems. *A*, bulb of onion cut through the center, × ½; *B*, rhizome of Solomon's seal, × ⅔; *C*, tuber of potato, × ½.

glory, or climbing by means of anchoring roots, tendrils, or hooks. Some plants have underground stems, such as *rhizomes*, *tubers*, and *bulbs*[1] (Fig. 49). These serve as food-storage organs, resembling storage roots in this respect.

[1] A bulb is really an enlarged fleshy underground bud consisting of a very short stem covered with either thickened scales or thickened leaf bases. The food is stored principally in the scales or in the leaf bases.

According to the duration of their aerial parts, plants are said to be either *herbaceous* or *woody*. An *herb* is a plant whose above-ground parts (ordinarily comprising the entire shoot system) die at the end of the growing season, while woody plants —*shrubs* and *trees*—have aerial stems that live from year to year. If the entire plant lives through but one summer, it is called an *annual.* Most herbs are annuals. A *biennial* is an herb that lives through two growing seasons. Its subterranean parts (roots or underground stems, as the case may be) accumulate food during the first growing season and live over the winter, but the upper portion of the plant commonly dies back to the ground in the autumn. The next year the plant sends up a new shoot, produces seed, and completes its life cycle. A *perennial* is a plant that lives for more than two years. Some herbs and all woody plants are perennials. A *herbaceous perennial* is a plant whose underground parts live from year to year, but whose aerial portion dies at the end of each growing season. Well-known plants of this sort are asparagus, rhubarb, goldenrod, iris, dahlia, canna, tulip, gladiolus, and many others.

The manner in which a plant branches is an important factor in determining its habit. In some plants the main stem is unbranched, the terminal bud being the only one that expands. Although rather common among herbs, an unbranched shoot system is rare among trees, but is seen in the palms, whose habit is said to be *columnar.* In many herbs and in such trees as the pine, spruce, fir, and Carolina poplar, the main stem continues to the top as a straight vertical shaft, the branches growing out horizontally from it. Such trees have a conical form. This type of branching, designated as *excurrent,* results from the persistent development of the terminal buds. In such trees as elm and oak, the main stem soon gives rise to large branches and does not continue to the top. Such trees have a spreading crown. This type of branching, called *deliquescent,* arises from the vigorous development of lateral buds, the terminal bud generally not expanding at all.

Stem Structure.—Based on their internal structure, the stems of seed plants belong to two general types. The first is characteristic of all gymnosperms and of those angiosperms whose seeds have two cotyledons (dicotyledons). The second and less common but more advanced type is found among those angiosperms whose seeds have one cotyledon (monocotyledons).

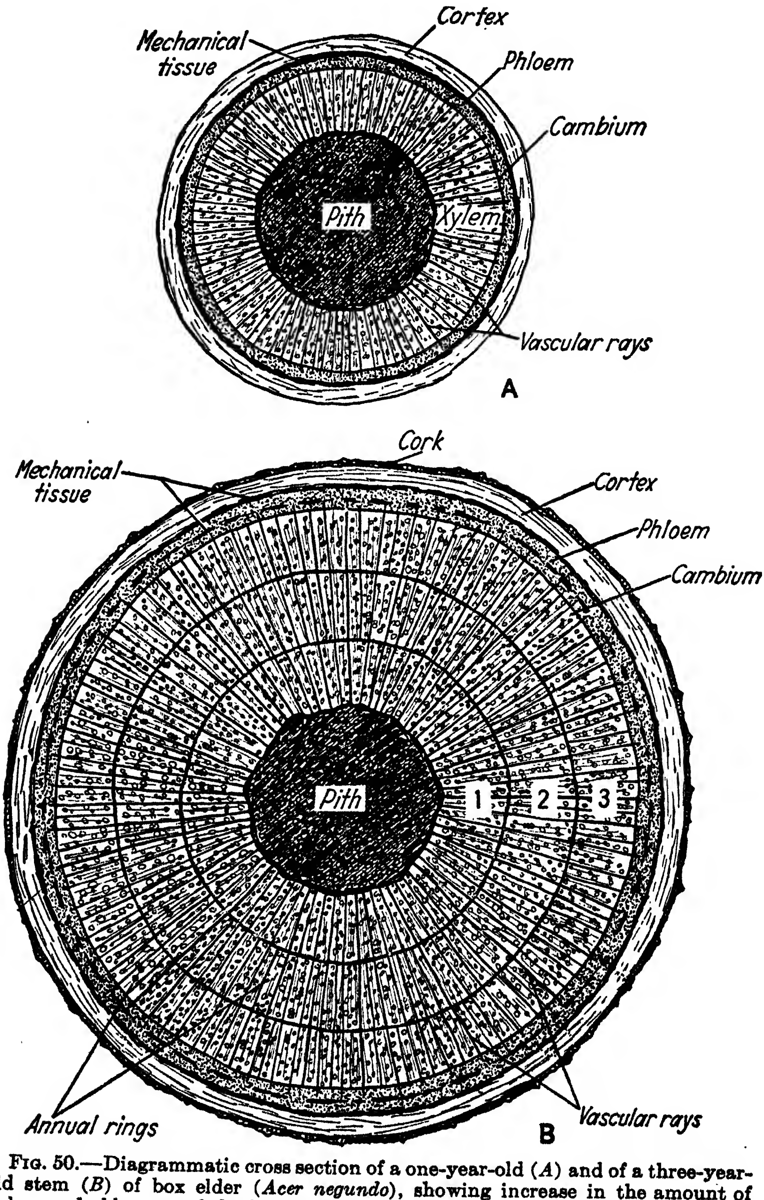


Fig. 50.—Diagrammatic cross section of a one-year-old (*A*) and of a three-year-old stem (*B*) of box elder (*Acer negundo*), showing increase in the amount of xylem and phloem, and the formation of cork, × 10. 1, 2, 3, successive layers of wood (xylem) formed during the three growing seasons of the stem's existence.

Young Woody Stem.—A cross section of a typical young woody stem, such as that of a box elder, shows three general regions: (1) an outer *cortex;* (2) a hollow *vascular cylinder;* (3) a central *pith* (Fig. 50*A*). Both the cortex and pith are composed chiefly of *parenchyma,* the same kind of tissue that occurs in the cortex of the root. The pith is colorless, but most of the cortical cells contain chloroplasts. As in a young root, the cortex is bounded externally by a layer of living cells called the *epidermis,* but here the outer walls of the epidermal cells have a waxy covering, forming a *cuticle.* This renders the epidermis waterproof, checking evaporation from the underlying tissues (Fig. 52*A*). Epidermal cells are living, but nearly always lack chloroplasts.

The vascular cylinder is generally a continuous tube, consisting chiefly of *xylem* tissue, but surrounding the xylem there is always a narrow zone of *phloem.* As in the root, both xylem and phloem are conductive in function, but the former also gives strength to the stem. Water with its dissolved soil salts passes upward through the xylem tissue from the roots to the leaves, while food in solution passes downward through the phloem. Traversing the vascular cylinder are a number of narrow plates of parenchyma cells called *vascular rays;* these extend from the pith to the cortex, but each runs only a short distance vertically. The vascular rays often store food and aid in the radial movement of substances in the stem.

Increase in Diameter.—Lying between the xylem and phloem of a young woody stem is a layer of thin-walled cells called the *cambium,* which typically appears as a continuous ring when seen in cross section (Fig. 50*A*). During the growing season, the cells forming the cambium are constantly undergoing division, giving rise to new vascular tissues—to new xylem outside the old xylem, and to new phloem inside the old phloem (Fig. 51). In woody plants the old phloem gradually disappears, but the xylem persists from year to year. The xylem consists of a series of concentric layers formed during successive growing seasons (Fig. 50*B*). Generally each layer is sharply delimited from the others, constituting an *annual ring,* the number of which indicates the age of the stem. The cambium produces larger xylem cells in the spring than in the summer, and none at all in the autumn and winter. So the line of contact between

the summer wood of one season and the spring wood of the next marks the boundary between successive annual rings. In

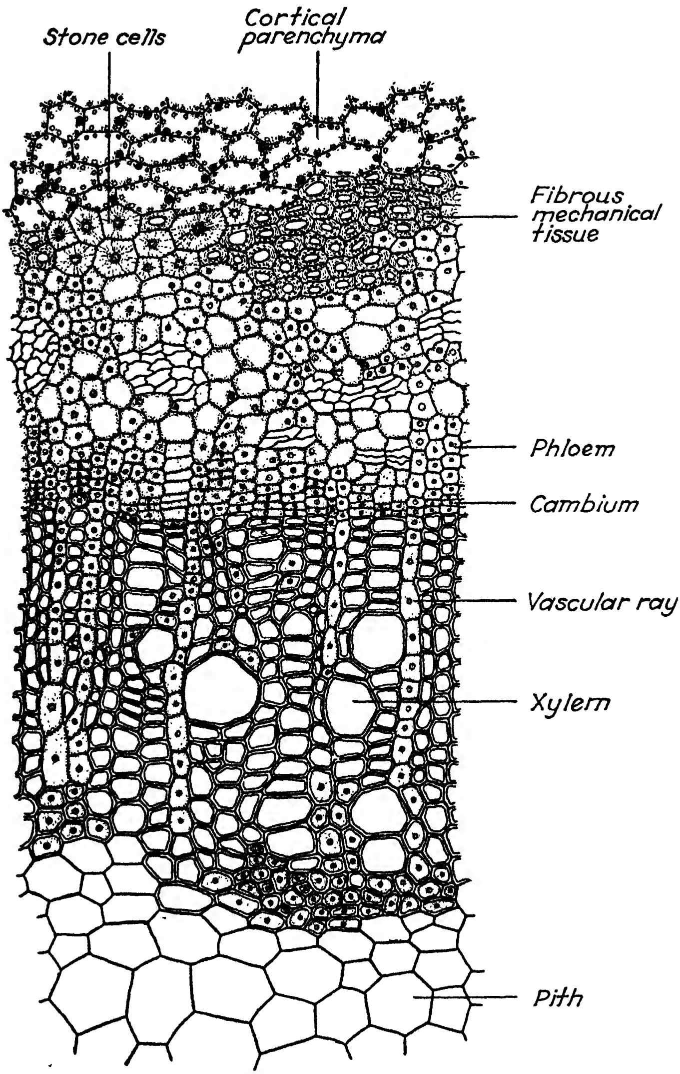


FIG. 51.—Portion of the vascular cylinder of a box elder stem in its first year of growth, showing structural details, × 300.

those tropical regions where uniform climatic conditions prevail throughout the year, most plants do not form annual rings.

As the vascular tissues increase in amount through cambial activity, *cork* develops outside the cortex, forming a protective external covering. It is produced by a cambium, which appears just beneath the epidermis. As in the root, cork tissue consists of layers of small cubical cells that lack protoplasmic contents when mature and have cell walls slightly thickened with a fat-like substance that renders them waterproof (Fig. 52). The cork contains numerous openings called *lenticels*, through which communication is maintained between the atmosphere and the living green cells of the cortex. Lenticels can readily be seen by examining the bark of almost any woody twig (Fig. 48).

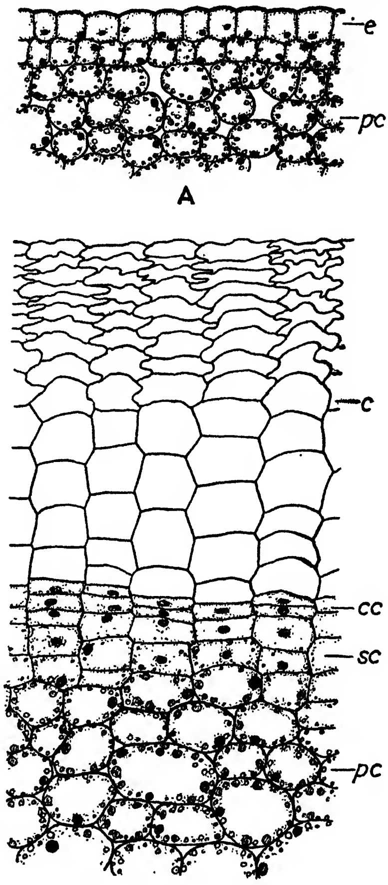


FIG. 52.—Development of cork in the stem of garden geranium (*Pelargonium hortorum*), × 150. *A*, cross section of outer portion of young stem; *B*, older stem; *e*, epidermis; *pc*, primary cortex; *c*, cork; *cc*, cork cambium; *sc*, secondary cortex.

After a number of years the cortex disappears, and because the pith always remains relatively small, an old woody stem really consists of only the following regions: *outer bark* (cork), *inner bark* (phloem and cambium), and *wood* (xylem). Conduction occurs only in the outer (younger) portion of the wood, the central (older) portion carrying no sap. The former constitutes the *sapwood*, the latter the *heartwood*.

Conducting Tissues.—The tissues designated as xylem and phloem are not uniform, but are differentiated into several kinds of elements. In practically all gymnosperms, as in pterido-

phytes, the xylem is made up of *tracheids*—slender, elongated, thick-walled cells generally pointed at either end and without living contents. Their cell walls are usually pitted. In angiosperms, tracheids are frequently present only in young stems, while other xylem elements occur in mature stems. The most important of these are *vessels*—long tubes of large diameter

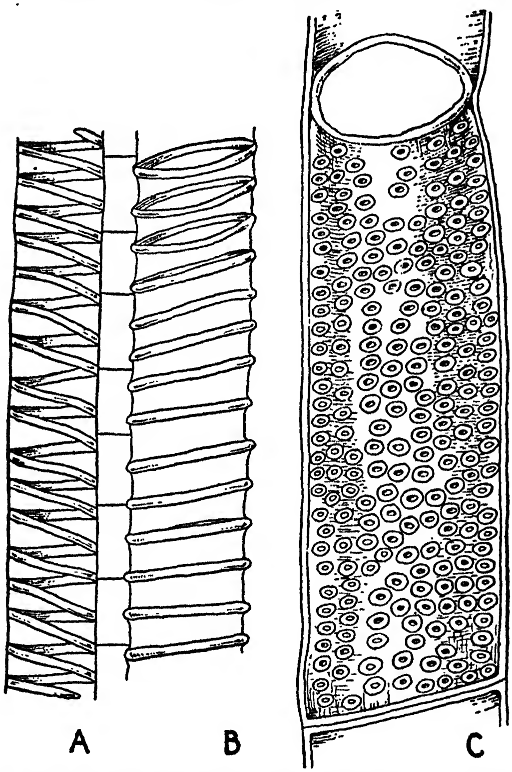


FIG. 53.—Spiral (*A*), annular (*B*), and pitted vessels (*C*) from stem of castor bean (*Ricinus communis*) as seen in longitudinal section, × 250.

that arise from a fusion of tracheids by a breaking down of their cross walls. Three chief types of vessels are found: *spiral*, *annular* or ringed, and *pitted*. These are distinguishable on the basis of the character of the thickenings on their walls (Fig. 53). The most important elements in the phloem are *sieve tubes*, so called because their end walls, and often side walls as well, are perforated like a salt shaker. Like tracheids, they are also elongated cells, but retain their protoplasm and thin walls.

Mechanical Tissues.—The function of mechanical tissues is to give rigidity, toughness, or hardness to plant organs. They are especially prominent where there is a weak development of xylem, as in many herbaceous stems. They have nothing to do with conduction. *Fibers* are long dead cells with pointed ends and uniformly thickened walls; they may occur in the cortex or in the vascular cylinder. *Stone cells* have very thick walls but are

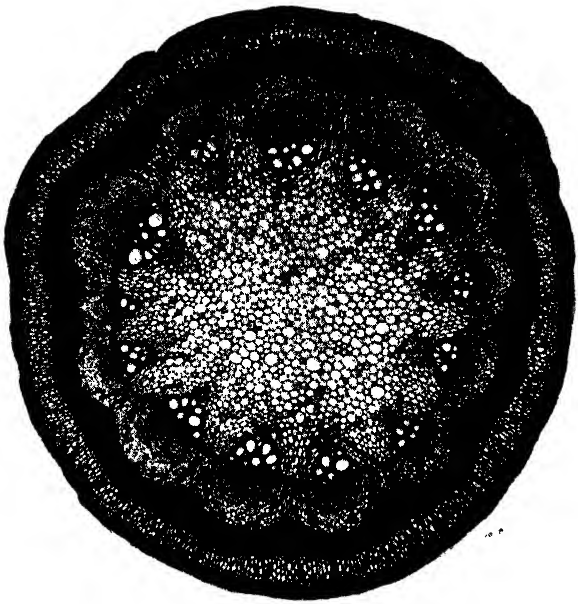


FIG. 54.—Cross section of a young stem of Dutchman's pipe (*Aristolochia macrophylla*), a woody vine, showing a vascular cylinder composed of isolated vascular bundles separated by wide extensions of the pith, × 20.

short; they often occur in isolated groups. Figure 51 shows both fibers and stone cells in the region between the phloem and cortex.

Herbs and Woody Vines.—Among dicotyledons the conducting tissues of herbs are greatly reduced in amount as compared with those of woody stems. This reduction may be a result of either diminished activity of the cambium or the breaking up of the vascular cylinder into separate strands called ***vascular bundles,*** between which are wide extensions of the pith. The same reduction of conducting tissues occurs in woody stems that climb (Fig. 54). In stems of this type, the cambium may connect the vascular bundles or not, but where it does, it often produces

only parenchyma between them. In many cases, however, the cambium later produces vascular tissues between the bundles, so that a continuous vascular cylinder is eventually formed.

Stems of Monocotyledons.—In angiosperms whose seeds have only one cotyledon, such as grasses, lilies, palms, and orchids, the stem has separate vascular bundles like the stem shown in Fig. 54, but instead of being arranged in the form of a hollow cylinder they are scattered irregularly through the stem (Fig. 55).

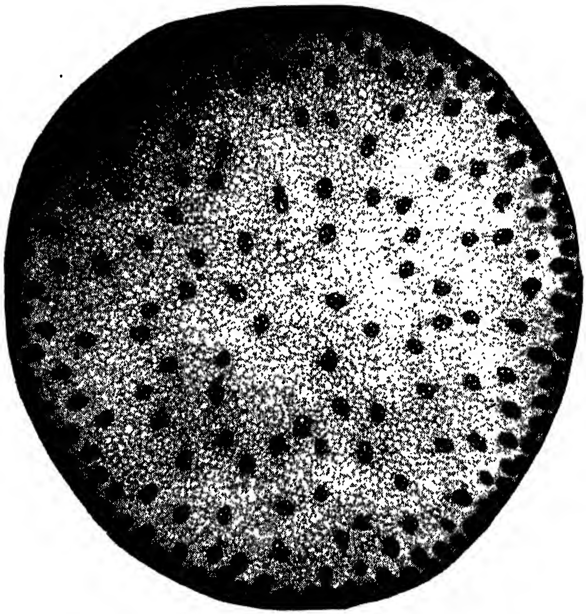


FIG. 55.—Cross section of a young corn stem (*Zea mays*), showing scattered vascular bundles, × 8.

A cornstalk, an asparagus stem, or a piece of sugar cane would serve as an excellent example of this type of stem. Between the scattered vascular bundles is parenchyma. Since no vascular cylinder is formed, there can be no distinction between pith and cortex. Each vascular bundle consists of a small group of xylem and phloem cells. The stems of nearly all monocotyledons lack a cambium, and consequently the vascular tissues, once formed, do not increase in amount. Increase in diameter takes place entirely by growth of the parenchyma between the vascular bundles.

THE LEAF

Leaves are typically thin expanded organs that arise as lateral outgrowths from a stem tip. They are the most conspicuous members of the vegetative plant body and carry on the major part of the work of nutrition. Their primary function is *photosynthesis*, the manufacture of carbohydrate food. This

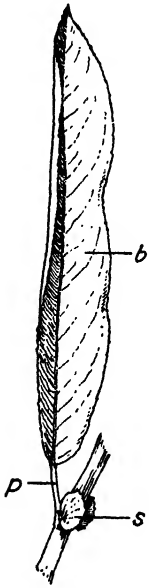


FIG. 56.—A willow leaf attached to its stem, showing blade (*b*), petiole (*p*), and stipules (*s*), one-half natural size.

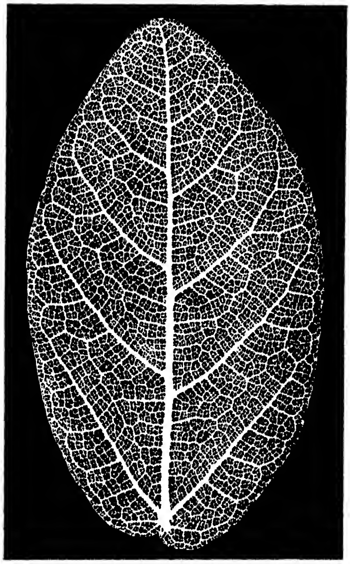


FIG. 57.—Leaf blade of climbing fig (*Ficus pumila*) which has been "skeletonized" by removal of the green tissue, natural size. The smallest veinlets may be seen with the aid of a magnifying lens.

requires that they be structurally adapted to the display of green tissue to the light.

External Features.—Most leaves are differentiated into a broad flat portion, the *blade*, and a slender leafstalk or *petiole* (Fig. 56). The blade is the more essential part of the leaf, the petiole merely supporting the blade and placing it in a favorable position with reference to the light. In fact, the leaves of many plants do not have a petiole, the blade then being

attached directly to the stem and constituting the entire leaf. Some leaves possess a pair of *stipules*—small, scale-like appendages formed at the base of the leaf, one on each side.

A noteworthy feature of leaves is the elaborate system of *veins*, which extends from the petiole to all parts of the blade (Fig. 57). Veins represent a continuation of the vascular system of the root and stem and so are channels for the transport of water and dissolved substances that pass into and out of the leaf. They also give the leaf some degree of rigidity. The larger veins of most leaves are conspicuous, especially on the lower

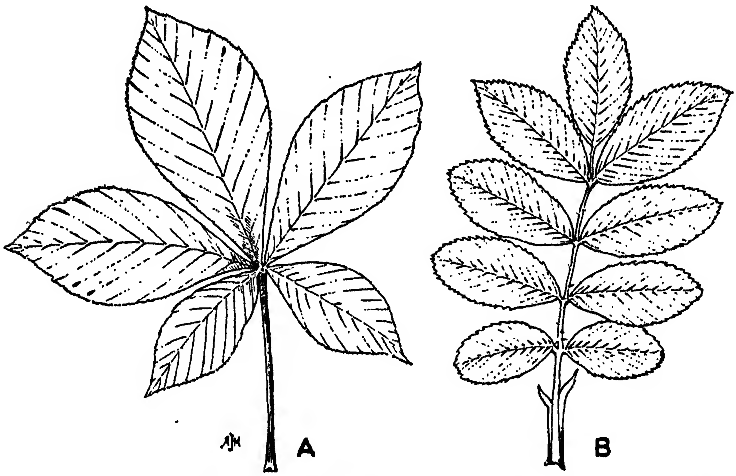


FIG. 58.—Divided leaves of horse chestnut (*A*) and of rose (*B*), one-half natural size.

side of the blade, but the smaller ones cannot be seen without the aid of a strong magnifying lens. In *net-veined* leaves, the larger veins give rise to smaller and smaller branches, ultimately ending freely in the green tissue (Fig. 57). In *parallel-veined* leaves, on the other hand, the principal veins (and often the only ones) run parallel to one another, generally from the base of the blade to the apex, as in a blade of grass. Net-veined leaves occur chiefly among dicotyledons, parallel-veined leaves mainly among monocotyledons.

In size, leaves vary from minute scales to those as large as in the bananas and palms. In form, some leaves are more or less circular, as in the geranium and nasturtium; others are long and narrow, like a grass blade or a pine needle; but most leaves are

of some intermediate shape. The leaf margin may be smooth and even, or variously toothed, notched, or lobed. In some cases the lobes are so deep that the blade is divided into separate *leaflets* (Fig. 58). Leaves also show great variation in thickness, texture, character of the surface, arrangement of the principal veins, and other features.

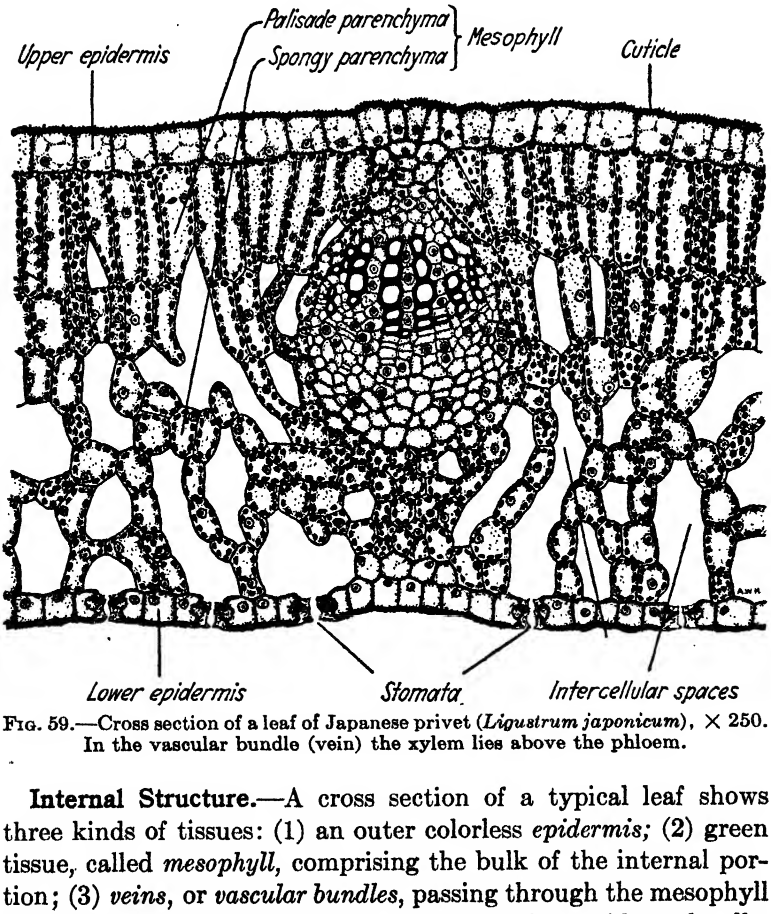


FIG. 59.—Cross section of a leaf of Japanese privet (*Ligustrum japonicum*), × 250. In the vascular bundle (vein) the xylem lies above the phloem.

Internal Structure.—A cross section of a typical leaf shows three kinds of tissues: (1) an outer colorless *epidermis;* (2) green tissue, called *mesophyll,* comprising the bulk of the internal portion; (3) *veins,* or *vascular bundles,* passing through the mesophyll (Fig. 59). Typically a single layer of living epidermal cells, lacking chloroplasts, is seen on both the upper and lower surface of the leaf. As in a young stem, their walls are covered with a thin waxy deposit that forms a *cuticle.* This makes the epidermal cells impermeable to water and gases, preventing exces-

sive loss of water from the inner tissues. Here and there are peculiar openings called *stomata,* which in horizontal leaves are usually entirely or largely confined to the lower surface. They are very numerous, there being commonly 100,000 or more to the square inch.

Stomata may easily be studied by stripping off a piece of lower epidermis from a leaf of a geranium or a lily and examining it under the microscope (Fig. 60). A stoma consists of a slit-like opening bounded by a pair of *guard cells.* These differ from the other epidermal cells in having chloroplasts. It is through

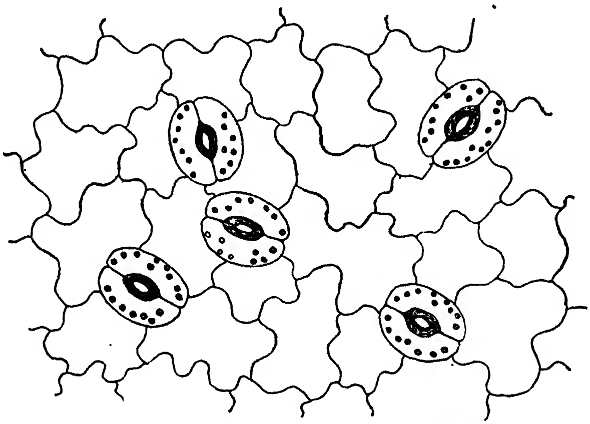


FIG. 60.—Portion of lower epidermis removed from a geranium leaf (*Pelargonium*), showing five stomata scattered among the ordinary epidermal cells, the latter having wavy outlines, × 500. Each stoma consists of a slit-like opening bounded by a pair of guard cells.

the stomata that gases pass from the atmosphere into the leaf and *vice versa.* In many leaves the size of the stomatal opening can be altered by a change in the shape of the guard cells, thus affecting the rate of gas exchange. Stomata are also present in the epidermis of young stems.

The mesophyll is the great food-manufacturing region of the leaf. It is typically differentiated into two kinds of tissues: *palisade parenchyma* and *spongy parenchyma,* the former usually forming a single layer beneath the upper epidermis. The two kinds of parenchyma differ from each other in the form and arrangement of the cells, but both have chloroplasts. Palisade cells are rather compactly arranged and are elongated at right angles to the surface of the leaf. The spongy tissue is composed

of cells loosely arranged, rather irregular in form, and with large intercommunicating air passages between them known as *intercellular spaces.* These communicate with the atmosphere through the stomata, and provide for a movement of gases throughout the leaf.

Each vein consists of a single vascular bundle in which the xylem occurs on the upper side, the phloem underneath. Around each bundle there is usually a *bundle sheath* composed of colorless parenchyma cells, its thickness being proportionate to the size of the vein. Often mechanical tissue is present in the vicinity of large veins, its function being to give rigidity to the leaf.

CHAPTER VI

REPRODUCTION IN SEED PLANTS

The reproductive features of spermatophytes, as compared with those of the lower plants, are very striking. Complications have arisen by the development of a number of modifications incident to the formation, protection, and dissemination of seeds, and for this reason the structures associated with reproduction are very different from those of the lower plants. Seeds are complex organs, their formation involving both asexual and sexual reproduction. In all spermatophytes the vegetative body, with its roots, stems, and leaves, is a sporophyte, arising from a zygote and in turn producing spores. Moreover, all seed plants are heterosporous, bearing microspores and megaspores, a feature which is rare among pteridophytes. In fact, it is heterospory which makes seed formation possible. Seeds are not organs of reproduction, but of dissemination, while fruits merely protect the seeds and frequently assist in their dispersal. The reproductive organs of the sporophyte are found in the cones of gymnosperms, and in the flower of angiosperms. The latter will be discussed first.

THE FLOWER

A *flower* is a specialized shoot whose appearance is necessary to the ultimate production of seeds. All flowers arise from buds, as in the case of vegetative shoots and, similarly, may be either terminal or lateral in position; that is, a flower may be formed at the end of a stem or in the axil of a leaf or scale. A cluster of flowers is called an *inflorescence,* and of these there are many kinds. A longitudinal section of a very young flower bud reveals the fact that the floral parts originate as lateral outgrowths from a central axis in the same way that leaves arise from a vegetative stem tip. In such primitive flowers as those of the magnolia and buttercup, the central axis is somewhat elongated, as in a vegetative bud. In the great majority of flowers, however, the

axis remains short, forming what is known as the *receptacle,* and upon this the floral parts are borne in a succession of whorls.

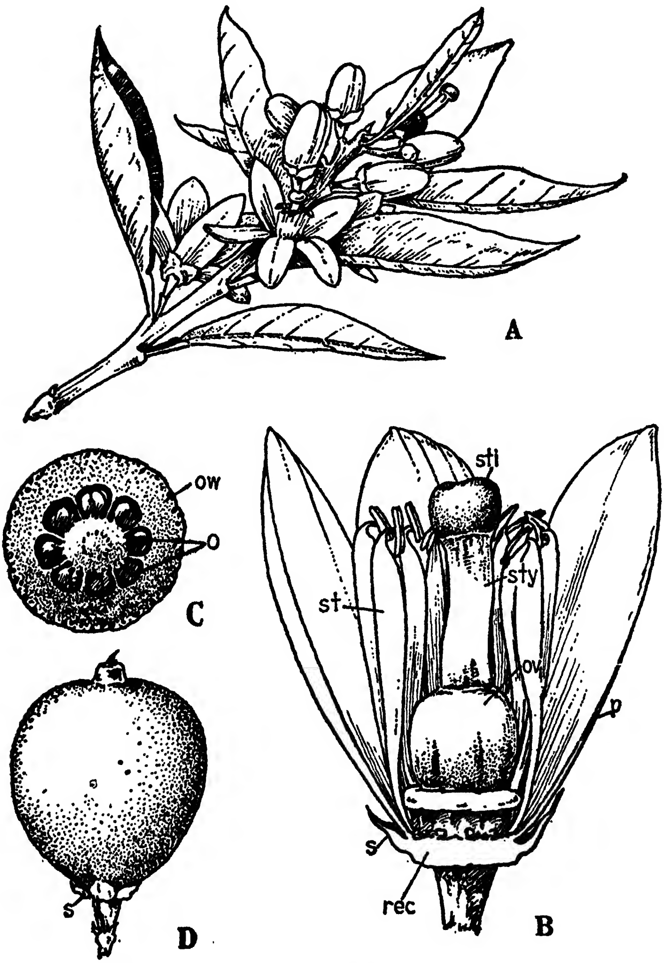


FIG. 61.—Flower and fruit of orange (*Citrus sinensis*). *A*, flowering shoot, × ½; *B*, single flower with two of the petals and several stamens cut away, × 2; *C*, cross section of the ovary, × 3; *D*, early stage in development of fruit, × 1; *p*, petal; *s*, sepal; *st*, stamen; *rec*, receptacle; *ow*, ovary wall; *o*, ovules; *sti*, stigma; *sty*, style; *ov*, ovary. The ovary, style, and stigma constitute the pistil.

Floral Parts.—A typical flower consists of four sets of parts symmetrically arranged with reference to one another (Fig. 61). The outermost set, constituting the *calyx*, is composed of indi-

vidual *sepals*. Ordinarily these are small, green, leaf-like parts that enclose and protect the other floral parts in the bud. The next set, occurring just inside the calyx, is the *corolla*, made up of individual *petals*. Most commonly the petals are large and conspicuous, being either white or of some color other than green. The petals, as well as the sepals, may either be separate and distinct from one another (*choripetalous*) or more or less united to form a tube (*sympetalous*). Moreover, all the petals may be alike in size and form (*regular*) or unlike (*irregular*).[1] The calyx and corolla, taken collectively, constitute the *perianth*.

The third floral set comprises the *stamens*, which occur inside the corolla. A stamen is generally a club-shaped organ consisting of a stalk or *filament* supporting a terminal *anther*. The latter contains two chambers, each representing a pair of fused sporangia, which in the young anther are distinct. These contain numerous *pollen grains*, which are liberated when the anther is ripe (Fig. 63).

In the center of the flower is the *pistil*. Typically this is composed of a lower bulbous *ovary* and a slender stalk-like *style* arising from it (Fig. 61*B*). A portion of the style, usually its tip, is enlarged or otherwise modified and often is covered with hair or with a sticky secretion. This is termed the *stigma*. The ovary is a hollow organ enclosing one or more small bodies known as *ovules*, each of which is an incipient seed (Fig. 61*C*). In some flowers the pistil is *simple*, but in most cases it is *compound*, being made up of two or more simple pistils more or less united. In other flowers there may be several simple pistils entirely separate from one another. A simple pistil is often called a *carpel*, and so a compound pistil is composed of individual carpels. In some flowers the ovary is *superior*, being situated at the top of the receptacle, inside of and entirely free from the other floral parts (Fig. 61*B*). In other flowers the ovary is *inferior*, or sunken in the receptacle, so that the other floral parts appear to arise from its summit.

Although most flowers contain both stamens and pistil, in some plants two kinds of flowers are produced, one lacking stamens and the other a pistil. The two kinds may be borne on the same

[1] A trillium (Fig. 38*B*) is choripetalous and regular; a nasturtium (Fig. 198), choripetalous and irregular; a petunia (Fig. 200), sympetalous and regular; a snapdragon (Fig. 202*B*), sympetalous and irregular.

plant, as in corn, squash, and castor bean, or on separate plants, as in the willow, poplar, and hemp. Some flowers have no corolla, others neither corolla nor calyx.

Pollination.—In order that the ovules may develop into seeds, pollen must first be transferred from a stamen to the pistil. In

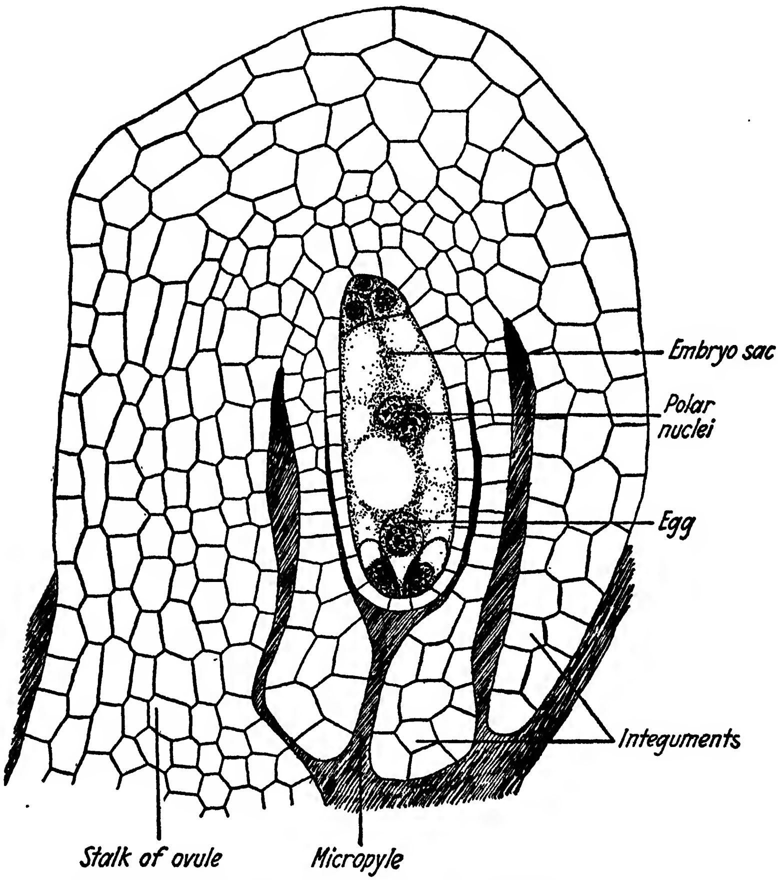


FIG. 62.—Longitudinal section of a lily ovule (*Lilium*) containing a mature embryo sac, × 250.

angiosperms pollen is deposited on the stigma. This act of *pollination*, as it is called, is accomplished in various ways, such as by direct contact, by wind, by insects, etc., depending on the kind of flower. Pollen may be transferred from a stamen to the pistil of the same flower (*self-pollination*) or to the pistil of

another flower of either the same plant or another plant (*cross-pollination*). Pollination is discussed in greater length in a later chapter (see pp. 296–299). The stamens and pistil are called the *essential organs* of the flower, because they are primarily involved in seed formation. The sepals and petals are known as *accessory organs*, since they play an incidental part. In fact, seeds may be produced whether a perianth is present or not.

Ovule and Embryo Sac.—The ovule, which is really a sporangium, has a characteristic structure essentially the same in all

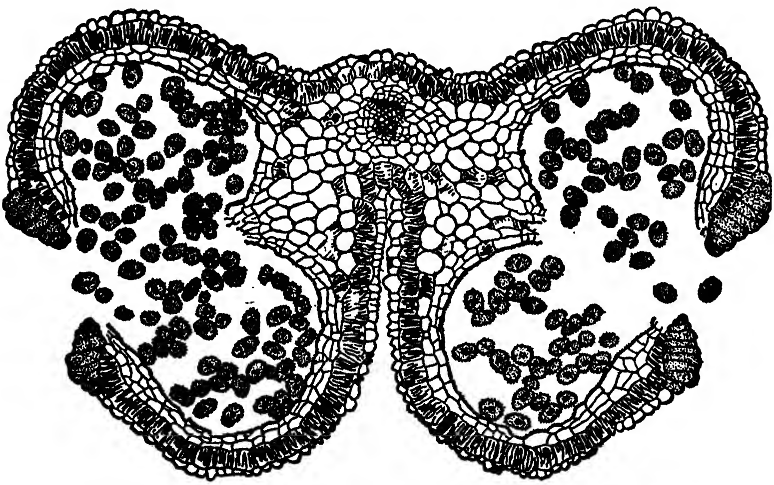


FIG. 63.—Cross section of a mature anther of lily (*Lilium*) just as the pollen grains (microspores that have begun to germinate) are being shed, × 30. (*From Chamberlain, "Elements of Plant Science."*)

seed plants (Fig. 62). It is attached to the inside of the ovary by means of a short stalk. The outer portion consists of one or two *integuments*, which do not completely invest the ovule, but leave a narrow passageway at one end called the *micropyle*. Within the cells of the young ovule, a linear row of four megaspores arises. Ordinarily three of these degenerate, and one enlarges to form the *embryo sac*. It should be noted that the functional megaspore does not leave the ovule to germinate, for it is this feature that makes possible the subsequent formation of a seed.

The embryo sac of angiosperms is organized in a peculiar way (Fig. 62). At each end are three small naked cells, each containing a nucleus; the middle one of the three at the micropylar end is

the *egg*. In the center of the embryo sac are two nuclei, called *polar nuclei*, in contact with each other. These eight nuclei have arisen by three successive divisions from the nucleus of the megaspore (Fig. 65*A* and *B*).

Pollen and Pollen Tube.—The pollen grains are formed in sporangia within the anthers (Fig. 63). At first each consists of a single uninucleate cell with a rather heavy, two-layered cell wall, being in reality a microspore. The microspores, like the megaspores, are formed in groups of four, but all of them mature. As a rule, before the pollen grains are liberated from the anther, the single nucleus divides to form a *tube nucleus* and a

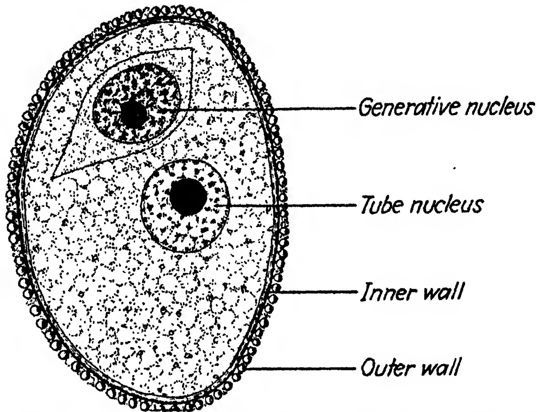


FIG. 64.—Section of a pollen grain of a lily (*Lilium*) in the shedding condition, × 750. The generative nucleus is surrounded by a small amount of cytoplasm and a plasma membrane, and so is organized as a naked cell.

generative nucleus, the latter commonly being organized as a small naked cell (Fig. 64). Upon reaching the stigma, each pollen grain puts forth a long tube that grows down the inside of the style. After reaching the cavity of the ovary, this *pollen tube* grows along the ovary wall until it reaches one of the ovules. This it then enters through the micropyle. Although many pollen grains may germinate on the stigma, only one pollen tube enters each of the ovules present in the ovary. While the tube is developing, but sometimes earlier, the generative nucleus gives rise to two *male nuclei*, which may or may not be organized as naked cells. The tube nucleus finally disintegrates.

Fertilization.—The pollen tube penetrates the embryo sac and discharges into it the two male cells, or male nuclei, as the case

may be. The male cells are really sperms, but in all seed plants except a few primitive gymnosperms, they are non-ciliated. One of the male nuclei penetrates the egg, forming a zygote. The other undergoes a unique performance in angiosperms, joining

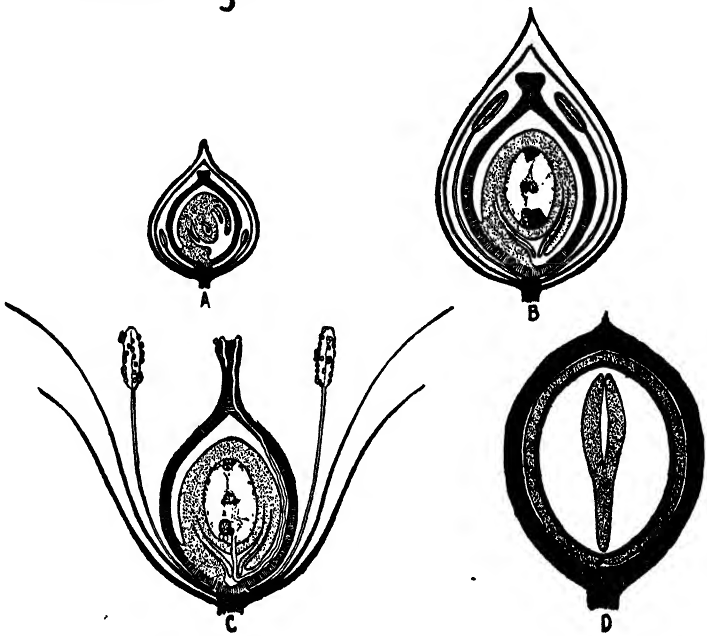


FIG. 65.—Diagrams illustrating the formation of the fruit and seed. The calyx and corolla are shown in solid black; the ovule, testa, and embryo dotted; the ovary wall and style lined. The ovary contains a single ovule. *A*, young bud, the ovule containing a single megaspore; *B*, bud ready to open. The megaspore has produced an embryo sac with its egg cell below and the two polar nuclei in the center; *C*, fully opened flower. The anthers have burst and pollination has taken place. Two pollen grains have germinated, and the pollen tube from one of them has penetrated the ovule and discharged its two male nuclei into the embryo sac. One male nucleus is shown uniting with the egg, the other with the two polar nuclei. *D*, ripe fruit. The calyx, corolla, and stamens have dropped off; the ovary wall has formed the wall of the fruit; the outer portion of the ovule has formed the testa of the seed; the zygote has given rise to the embryo, the endosperm nucleus to the abundant endosperm tissue (shown in white) which surrounds the embryo. (*From Sinnott, "Botany; Principles and Problems."*)

the two polar nuclei in the center of the embryo sac; then all three nuclei fuse to form the *primary endosperm nucleus* (Fig. 65*C*). The other cells in the embryo sac are functionless and soon disappear. Following fertilization, the petals and stamens wither and drop off, and often the sepals do likewise. The ovary

enlarges to form a fruit, and the contained ovules are transformed into seeds.

Alternation of Generations in Seed Plants.—The relation of the reproductive structures of spermatophytes to those of the lower plant groups is somewhat difficult to understand unless a more extensive study is made than has been outlined in the present chapter. It should be noted, however, that the vegetative body of seed plants is a sporophyte, producing two kinds of spores: *microspores* (small) and *megaspores* (large), both being formed in sporangia. The microspores arise in large numbers within the anther, and, although four megaspores arise within each ovule, only one is functional. The microspores are shed, but the megaspores are not.

As in the heterosporous pteridophytes, two kinds of gametophytes occur. The contents of the pollen tube, arising from a microspore, represent a greatly reduced *male gametophyte,* while the embryo sac, developed by a megaspore, is really a *female gametophyte.* Both kinds of gametophytes are small, obscure, colorless, and entirely dependent for nourishment upon the sporophyte. The zygote, resulting from the fusion of a male with a female cell, gives rise to the sporophyte, thus completing the life cycle.

Embryo and Endosperm.—The fertilized egg, or zygote, germinates within the ovule, and from it there arises, by the processes of growth, an *embryo,* or rudimentary plant. At the same time the primary endosperm nucleus, originating by a triple nuclear fusion, gives rise to *endosperm,* a nutritive tissue that surrounds the embryo and contains stored food. The embryo does not proceed very far in its development before it goes into a dormant state. Meanwhile the integuments of the ovule harden to form a tough outer covering, and the ovule becomes a *seed* (Fig. 65*D*). In some angiosperms the food stored in the endosperm is entirely absorbed by the developing embryo, so that the mature seed has none; but in many other angiosperms the endosperm persists.

The Fruit.—After fertilization has taken place and the ovules are ripening into seeds, the ovary itself enlarges and undergoes other changes that result in the formation of a fruit (Figs. 61 and 65*D*). A *fruit* consists essentially of a ripened ovary, but in some cases associated parts also enter into its formation.

If only the ovary is involved, a *true fruit* results, but if other parts are included, an *accessory fruit* is formed. For example, in the apple the ovary forms the inner portion of the "core," the fleshy part of the fruit developing chiefly from the receptacle, which grows up around the ovary. In the strawberry, which also is an accessory fruit, a number of small ripened ovaries are embedded in the surface of a fleshy receptacle.

At maturity fruits may be fleshy, as in the tomato or grape, or dry as in the peanut. When dry, fruits may split open, as a

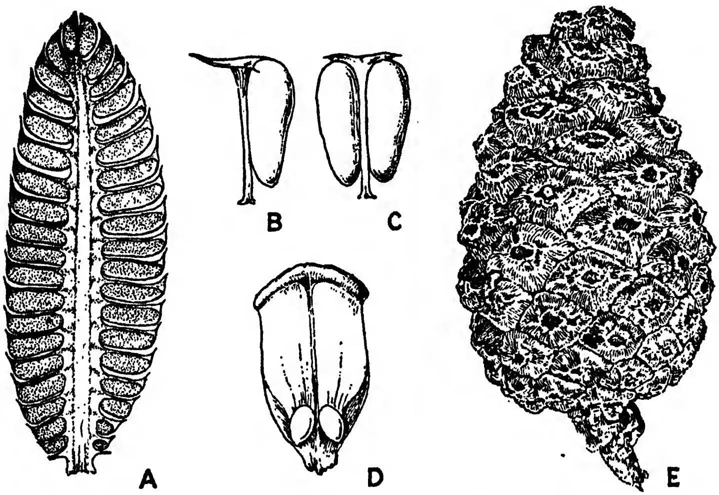


Fig. 66.—Pine cones and cone scales. *A*, longitudinal section of a staminate cone, each stamen bearing a pair of microsporangia on its lower side, × 4; *B*, side view of a single stamen; *C*, lower view of same; *D*, a single carpel bearing a pair of megasporangia (ovules) on its upper face; *E*, a carpellate cone, × 1½.

bean or pea pod, or remain closed, like an acorn. Fruits may be one seeded, like a peach, or many seeded, like a melon. Some fruits are thin skinned, as in the olive, or thick skinned, like an orange. In stone fruits, such as the cherry, peach, or plum, the ripened ovary wall forms two distinct portions: an outer fleshy and an inner stony one, the latter enclosing a single seed. Sometimes a group of fruits ripen together, becoming more or less consolidated to form an *aggregate fruit*, as in the blackberry and raspberry. "Seedless" fruits are unnatural products developed under man's influence.

Reproductive Features of Gymnosperms.—The reproductive features of gymnosperms and angiosperms are similar in many

respects, but different in others, gymnosperms being in general more primitive and consequently more like pteridophytes. Some of these important differences will now be noted.

Gymnosperms do not have true flowers, although the cones that they bear correspond to the flowers of angiosperms. In fact, flowers are thought to have been derived from cones. Gymnosperms, such as a pine, bear two kinds of cones: one made up of stamens, and the other of carpels. Both the stamens and carpels are scale-like and rather different from the corresponding parts

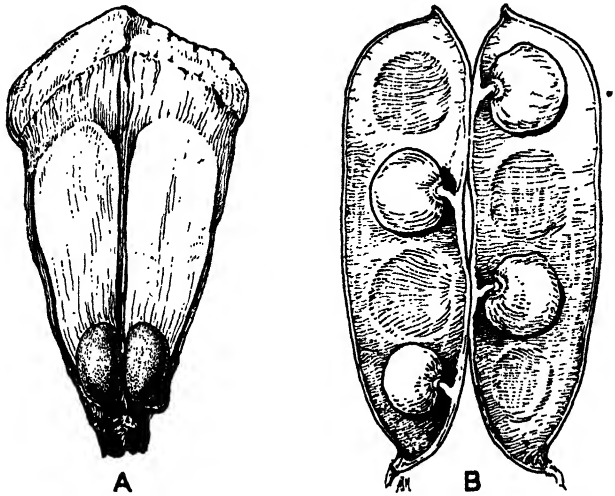


FIG. 67.—Gymnosperm and angiosperm compared. *A*, cone scale of sugar pine bearing two naked seeds at base of upper surface, natural size; *B*, pod of Lima bean split open to show the enclosed seeds, one-half natural size.

in angiosperms (Fig. 66). These cone scales are borne on an elongated axis, a condition retained by certain primitive flowers, as already noted. No perianth is present. The ovules, and hence the seeds as well, are not enclosed in an ovary but occur freely exposed on the flat face of a carpel (Fig. 67).

In gymnosperms the megaspore gives rise to a mass of tissue within the ovule that corresponds to the embryo sac of angiosperms but obviously is more primitive (Fig. 68). Moreover, it produces several archegonia at the micropylar end and thus is a true female gametophyte. Each archegonium contains a single egg. Since the ovules are not enclosed in an ovary, the pollen grains came in direct contact with them and so have only a

short distance to travel in order to reach the archegonia. The male gametophyte, contained in the pollen tube and developed from a pollen grain (microspore), produces as a rule only two male cells, but in addition to the tube nucleus there are several functionless cells. No antheridium is present. A remarkable feature of the cycads, which are the most primitive existing gymnosperms, is the presence of swimming sperms. Fertiliza-

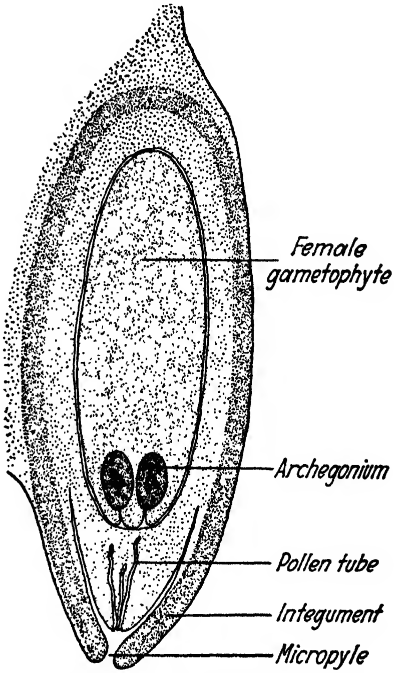


FIG. 68.—Longitudinal section of a pine ovule (*Pinus*) containing a mature embryo sac, × 15.

tion occurs as in angiosperms, but there is no triple fusion of nuclei to form endosperm. As a rule only one egg in each ovule gives rise eventually to a fully developed embryo.

The seed of gymnosperms is essentially similar to that of angiosperms, except that the endosperm, which is always present, represents female gametophyte tissue. Thus the food-storage tissue in the seeds of gymnosperms and of angiosperms, while called "endosperm" in both cases, arises in two distinctly different ways, in the former group appearing before fertilization, in the latter after fertilization.

THE SEED

A *seed* is a ripened ovule in which antecedent processes have resulted in the development of a dormant *embryo*, an outer seed coat or *testa*, and generally also a special food-storage region, the *endosperm*. The dormant condition of the embryo enables the seed to become detached from the plant that produced it and to remain viable until conditions are favorable for its renewed growth. Thus seeds are organs of dissemination, enabling plants to become distributed over a wide territory. They are commonly adapted to dispersal by some special means, as by currents of air or water, by animals, etc. (see pp. 295–296). Seeds are really not organs of reproduction, for reproduction takes place when fertilization of an egg results in the formation of a zygote from which the embryo develops. When a seed germinates, a new plant is not produced, but the embryo, which is the new plant, simply renews its growth.

Seed Structure.—All seeds have an embryo and nearly all have a testa, but when ripe many lack endosperm. In the pea, bean, sunflower, and squash the endosperm is entirely absorbed by the embryo during its early development, while in corn, wheat, morning-glory, buckwheat, and castor bean the endosperm remains in the mature seed and is not used by the embryo until germination begins.

The embryo consists of three main parts: (1) the *hypocotyl*, a very short stem that gives rise to a root at its lower end; (2) the *plumule*, a minute bud arising from the upper end of the hypocotyl; (3) one or more leaf-like *cotyledons*, attached to the upper end of the hypocotyl just below the plumule (Fig. 69). The seeds of many gymnosperms have a number of cotyledons, but all angiosperms have either two or one. On this basis angiosperms are divided into two great groups: the dicotyledons, with two cotyledons, and the monocotyledons with one. An interesting correlation is seen in the fact that dicotyledons have net-veined leaves and stems in which the woody tissue forms a hollow cylinder, while monocotyledons have mostly parallel-veined leaves and stems with woody tissue in scattered bundles.

Dormancy.—As already stated, seeds pass into a state of dormancy during the ripening process. Because they are organs of dissemination, the arresting of vital activities during dispersal is

a necessity. Dormancy is brought about primarily by the withdrawal of water. Although all mature seeds contain some water, the amount is small, being commonly 10 to 12 per cent by weight. Accompanying this water loss, important chemical changes occur, resulting in an almost complete cessation of all vital processes.

The length of time that seeds are capable of retaining their power of germination varies greatly. The seeds of willows die if they do not sprout within a few days after falling from the tree. Some seeds are able to grow as soon as ripe, but if conditions are unfavorable for growth, retain their viability for a long time. Most ripe seeds will not sprout immediately upon ripening, but

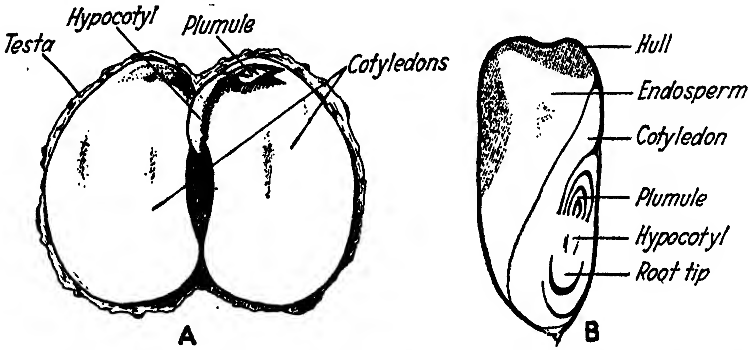


FIG. 69.—Seed structure. *A*, a Lima bean laid open to show the three parts of the embryo, × 1. There is no endosperm, the food being stored in the two large cotyledons. *B*, longitudinal section of a grain of corn, a seed without endosperm and with a monocotyledonous embryo, × 3. The outer covering consists of the ovary wall fused with the testa, and so the grain is really a one-seeded fruit.

must remain dormant for several months before germination can occur. If external conditions are then favorable, growth will proceed, but if not, the seeds of most plants will not retain their viability for more than a year or two. Few seeds will remain viable for more than 3 or 4 years after ripening, yet the seeds of some plants, notably of certain legumes, will germinate even if more than a hundred years old. Such cases, however, are extremely rare. Stories of viable wheat being taken from ancient Egyptian tombs have no scientific foundation; in fact, numerous experiments have proved that such seeds will not grow.

Conditions for Germination.—After a longer or shorter period of dormancy, if the embryo is still alive, germination begins by the resumption of growth and other activities within the seed.

This happens, however, only if three external conditions are satisfied: (1) The temperature must be favorable. (2) Abundant moisture must be available. (3) There must be an adequate supply of oxygen. If any one of these three conditions is not fulfilled, growth of the embryo cannot proceed.

Water and oxygen pass by osmosis through the testa into the seed. The absorption of water softens the seed coat and causes the seed to swell, often to twice its former size. The process of respiration, which previously was very feeble, now becomes greatly accelerated, being manifested in three ways: (1) There is always a vigorous gas exchange between sprouting seeds and the atmosphere, involving the absorption of oxygen and the liberation of carbon dioxide. (2) There is a decrease in the amount of reserve food, showing that it is being consumed by the embryo. (3) Heat is evolved by sprouting seeds, as can be shown by placing some of them with a thermometer in a vacuum bottle.

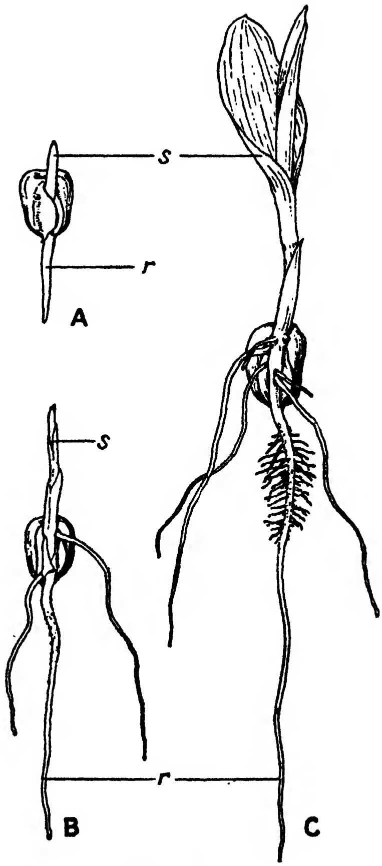


FIG. 70.—Successive stages in the development of a corn seedling, one-half natural size; *s*, shoot developing from plumule; *r*, primary root. The hypocotyl does not elongate and the cotyledon remains within the seed, acting as an absorbing organ.

Development of the Seedling.—The first external evidence of germination is the rupturing of the testa and the appearance of the root tip. The root grows straight downward and sends out root hairs into the soil. Soon short lateral roots appear, firmly anchoring the seedling. The primary root arises from the lower end of the hypocotyl. After it is formed, the

hypocotyl may remain short or it may undergo considerable elongation, depending upon the type of germination.

Corn, pea, and scarlet runner bean illustrate the first type of seedling development (Fig. 70). Here the hypocotyl does not elongate, and the cotyledon or cotyledons remain in the soil. The plumule gives rise to a shoot that pushes its way upward,

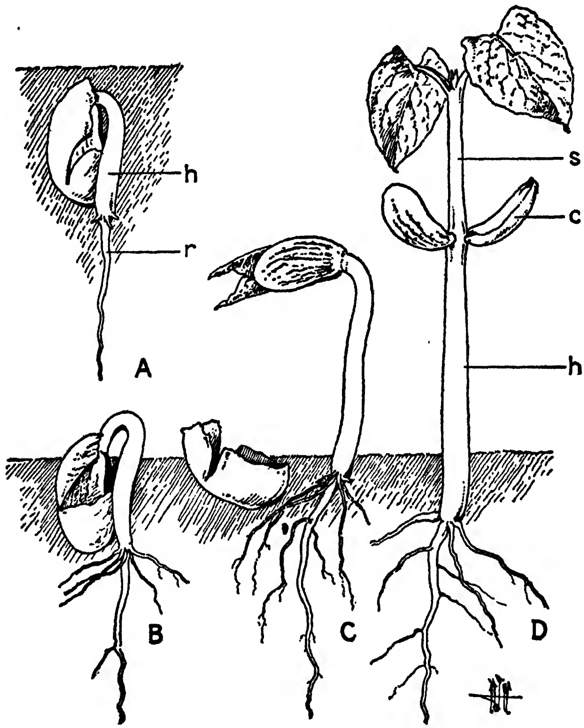


FIG. 71.—Successive stages in the development of a bean seedling, natural size. *h*, hypocotyl; *r*, primary root; *c*, cotyledon; *s*, shoot developing from plumule. By the elongation of the hypocotyl the cotyledons are pulled out of the soil, the development of the plumule being retarded until this is accomplished.

putting forth green leaves at the surface of the ground. The reserve food in the endosperm or cotyledons, as the case may be, contributes to the growth of the seedling until the roots have established a connection with the soil and the leaves have expanded to the light.

A more complex type of seedling development is seen in the common garden or kidney bean (Fig. 71). After the root has

formed at the lower end of the hypocotyl, the latter continues to grow as the root system is developed. At first the growth of the hypocotyl is uneven, resulting in the formation of a *hypocotyl arch.* The bent hypocotyl then straightens, pulling the cotyledons out of the testa and carrying them upward into the air. The plumule, situated between the cotyledons and up to this point relatively inactive, now gives rise to a leafy shoot. At the same time the cotyledons spread apart and turn green,

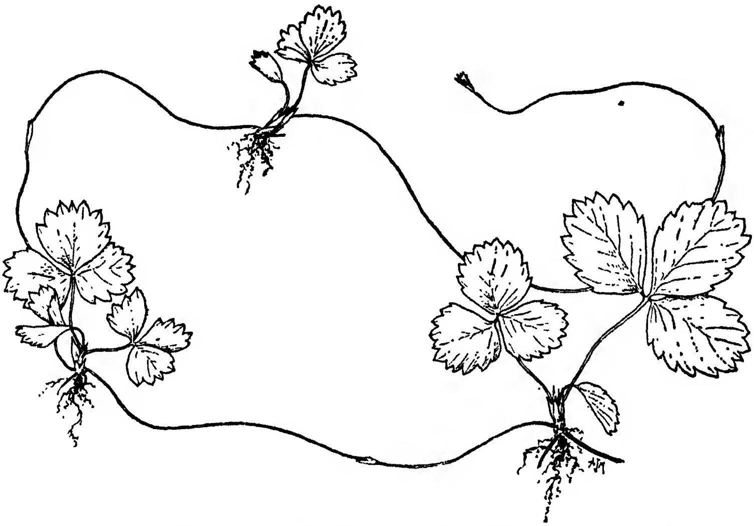


FIG. 72.—Strawberry, showing vegetative propagation by means of runners, one-half natural size. The dying away of the runners isolates the new plants that have arisen at the nodes. Note that only every other bud develops, the others remaining dormant.

but as soon as their food supply has been exhausted, they wither and drop off.

Other dicotyledons illustrating this second type of germination are the sunflower, maple, morning-glory, and castor bean. It is not so common among monocotyledons as the first type but is seen in the onion. Here the single cotyledon is pulled from the testa and functions as a photosynthetic organ until the first true leaves appear.

VEGETATIVE PROPAGATION

In many angiosperms reproduction may be brought about by a root, stem, or leaf. This is called *vegetative propagation*

because it involves merely the isolation of some vegetative part of the plant body. For example, in the strawberry, horizontal stem branches called *runners*, which creep along the ground, are produced. These send out roots and buds at the nodes, the older parts later dying away and isolating the new plants (Fig. 72). The formation of tubers in the common potato, of rhizomes in the iris and lily-of-the-valley, and of bulbs in the tulip and

Fig. 73.—Cutting of chrysanthemum, illustrating the formation of roots at the lower end of a branch previously removed from a mature plant and placed in soil.

onion are all means by which vegetative multiplication is accomplished (Fig. 49).

The planting of "slips" or "cuttings" is a method of vegetative multiplication extensively used by gardeners in propagating many cultivated plants (Fig. 73). Most commonly stem cuttings are planted, but in some cases root or even leaf cuttings are utilized. The "eyes" of a potato are nodes at which are two or more minute buds that give rise to new plants when pieces of

the tuber are put into the ground (Fig. 49*C*). In the practice of *budding* and *grafting*, a detached bud or twig of one plant is inserted into an incision made in another in such a way that the two will grow together. The wound is then wrapped or covered with wax until it is healed. The detached member becomes part of the plant on which it has been inserted, but always produces, of course, the same kinds of leaves, flowers, fruits, and seeds that it would have produced had it not been removed from its own plant. The practices of budding and grafting provide a means of propagating desirable races of plants, especially of fruit trees. In the case of seedless varieties, such as the navel orange, the use of some method of vegetative propagation obviously is a necessity.

CHAPTER VII

METABOLISM AND IRRITABILITY IN PLANTS

The term *metabolism* is applied to all processes in plants and animals that are concerned either with the building up or breaking down of protoplasm. In other words, it is the totality of physical and chemical changes by means of which the life of an organism is maintained. All processes in plants concerned with the manufacture and utilization of food, the release of energy, and the elimination of waste products are phases of metabolism. In general, any metabolic process may be either constructive or destructive, depending upon whether it contributes to the building up or to the breaking down of living matter.

Independent and Dependent Plants.—It has already been pointed out that all green plants have the power of making food by photosynthesis, and that plants which lack chlorophyll are unable to carry on this important function. Green plants are said to be *independent* because they nourish themselves, while *dependent* plants must absorb their food from some external source. All plants are independent except the fungi and a few angiosperms, such as the Indian pipe, dodder, and mistletoes (Figs. 221, 225, 226). Dependent plants that absorb food from dead organic matter are *saprophytes*, while those that subsist on other living organisms are *parasites*.

Independent plants support themselves. They build up food within their own bodies from water, carbon dioxide, and mineral salts—inorganic substances that they absorb from their environment. These are not foods themselves, but raw materials from which foods are constructed in the plant body. *Foods* are organic substances capable of yielding both energy and formative material that living things may employ in carrying on their vital processes. Inorganic substances cannot do this. Protoplasm, whether plant or animal, can derive energy from only three classes of substances: carbohydrates (starch, sugars, etc.), fats, and proteins. These are organic substances; they

alone yield nourishment; they alone can sustain life. Thus the food of all organisms is the same, the difference between green plants on the one hand, and animals and dependent plants on the other, arising from the manner in which they obtain their food. It is only green plants that can synthesize food from inorganic materials. Animals and dependent plants must obtain it from an external source—food that was originally formed in the body of a green plant. Green plants are the ultimate source of all nourishment, and without them no other forms of life could exist.

Absorption.—A green plant has two sources from which it derives substances essential to its existence, *viz.*, the air and the soil. Through its shoot system, especially its leaves, it obtains oxygen and carbon dioxide. Through its root system it absorbs water with oxygen and small quantities of certain mineral salts dissolved in it. The oxygen is used in respiration, the other substances in food manufacture. Oxygen and carbon dioxide enter the leaves and young stems through the stomata; they enter the older stems through the lenticels. Water and its dissolved substances are taken into the roots chiefly through the root hairs. Oxygen, carbon dioxide, water, and mineral salts are the only substances that a green plant absorbs from its environment. Organic matter in the soil, called *humus*, is not absorbed. That this contains nourishment is evidenced by the fact that such organisms as mushrooms and earthworms can live on it, but it is not a source of food for green plants. After humus is completely decayed, through the activities of saprophytes, it adds to the mineral content of the soil and thus enriches it for green plants, but while it is still undecomposed it is not utilized.

Diffusion.—All substances enter the plant by diffusion, a physical process that can easily be understood. When a crystal of copper sulphate is dropped into a glass of water, minute particles of the salt escape, as is evidenced by the dark-blue color assumed by the water around the crystal. If left undisturbed, gradually the colored area becomes more and more extensive, until finally the entire liquid is uniformly light blue, indicating that a complete mixing of the two substances has taken place. Then the salt is said to be dissolved, and a solution of copper sulphate in water is formed. This spontaneous intermingling of the particles of one substance with those of another

is called *diffusion* (Fig. 74). The direction of movement is always from a region where the particles of the dissolving substance are closer together to where they are farther apart, *i.e.*, from a place of higher to one of lower concentration. Diffusion is exhibited only by soluble substances. A lump of starch will not dissolve in water, and consequently there is no movement of its particles. If the liquid is shaken, a mechanical mixing occurs, but the starch soon settles to the bottom.

Osmosis.—*Osmosis* is the passage of water or of dissolved substances through a membrane and thus is a special kind of diffu-

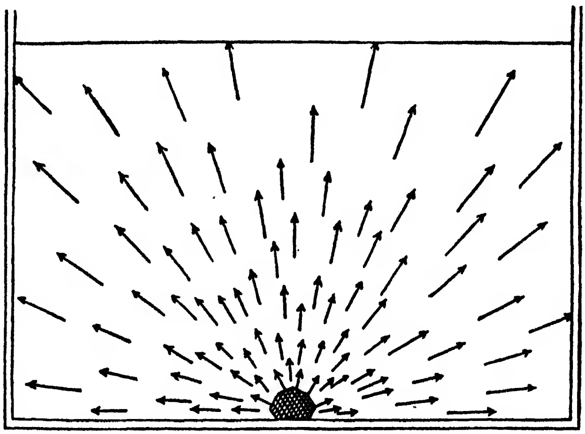


FIG. 74.—Diagram illustrating the diffusion of the molecules escaping from the surface of a soluble crystal placed in a vessel of water. (*From Sinnott, "Botany; Principles and Problems."*)

sion. When a salt solution is separated from pure water by a membrane through which the particles of both substances can pass, the salt particles diffuse into the pure water, and the water particles into the salt solution, as if no membrane were present. This movement continues until the concentration is the same on both sides of the membrane, that is, until there are approximately the same number of salt particles per unit volume on one side as on the other. With respect to any given substance, a membrane is said to be *permeable* if the substance can pass through it, and *impermeable* if it cannot.

Although practically all organic membranes are permeable to water, any given one is usually permeable to some dissolved substances and impermeable to others. Thus a thin piece of

parchment, placed between a salt solution and pure water, while permeable to the water particles, almost completely checks the free diffusion of the particles of salt. Under these conditions, practically no salt passes through the membrane into the water, but a peculiar thing happens—a great deal of water moves in the opposite direction, that is, into the concentrated solution (Fig. 75). As a result, the volume of the liquid increases on one side of the membrane and decreases on the other, and if the salt solution is in an enclosed space, a considerable pressure develops.

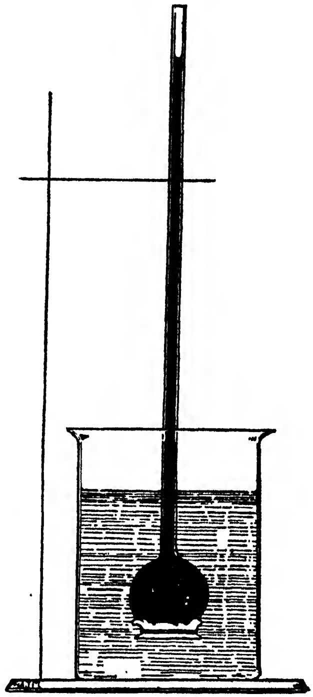


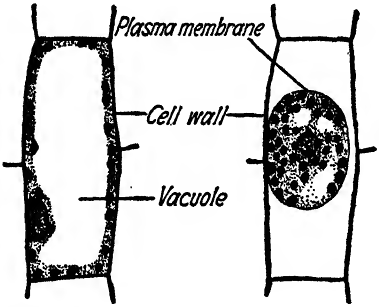
Fig. 75.—Demonstration of the osmotic movement of water. A parchment membrane is tied over the lower end of a thistle tube partially filled with a strong salt solution and immersed in a beaker of water. Water passes into the tube, causing a dilution of the salt solution and rise in its level.

An osmotic movement of water occurs whenever a strong solution is separated from a weaker one by a membrane that is permeable to the water but impermeable to the dissolved substance. The direction of movement is always from the solution of less to that of greater concentration of particles of dissolved substance, or, in other words, from the less dense to the more dense solution. A familiar illustration of this phenomenon is seen in the swelling of prunes or raisins when placed in water. The skin of the fruit, if unbroken, is impermeable to the sugar contained inside, and thus water enters. But if the swollen fruit is put into a strong syrup or a strong brine, water is withdrawn and it again shrinks.

It is by osmosis that all substances enter and leave all living cells. The cell wall that surrounds most plant cells is permeable to water and to practically all dissolved substances, but the plasma membrane is permeable to some substances and impermeable to others. Thus sugar in a root hair cannot pass into the soil, but any given soil salt, under certain conditions, may enter.

The entrance of water depends upon the total concentration of dissolved substances on each side of the plasma membrane. It is important to understand that the particles of water and of dissolved substances move independently of one another, both into the root and from cell to cell.

Plasmolysis.—If a living cell is in contact with water or a very weak solution, water enters because the concentration of dissolved substances is greater inside than outside the cell. But if placed in a stronger solution of a substance to which the plasma membrane is impermeable, such as common table salt, water passes out of the cell. As a consequence, the plasma membrane, being elastic, shrinks away from the cell wall and the protoplasm forms a spherical mass within the cell cavity (Fig. 76). This behavior is known as *plasmolysis*. If the cell is not left too long in the salt solution, it will regain its normal appearance when put back into pure water.



A B

Fig. 76.—Demonstration of plasmolysis. *A*, normal cell of leaf of *Elodea*, × 250; *B*, the same after 5-minute immersion in a 2 per cent solution of sodium chloride, showing the contraction of the plasma membrane caused by a withdrawal of water from the cell.

Conduction and Transpiration.—The cell sap of the root hairs contains certain dissolved substances to which the plasma membrane is impermeable, especially sugar, and is relatively more highly concentrated than the soil water. So an osmotic movement of water into the root hairs occurs. Dissolved substances also may diffuse into the root if the plasma membrane is permeable to them and certain other conditions are favorable. After entering the root hairs, the soil water and its dissolved substances pass through the living cells of the cortex by osmosis. Upon reaching the vascular cylinder, a mass movement of water and solutes takes place upward through the xylem tissue into the stem and out into the leaves. Xylem, it will be recalled, consists almost entirely of cells that have no protoplasm. They are greatly elongated, thick-walled tubes, and thus the ascending water with its dissolved substances (sap) moves through cavities in

dead cells. Such a mass movement is much more rapid than an osmotic movement through living cells would be.

Upon reaching the leaves, nearly all the water that has traveled upward through the stem is evaporated through the stomata.

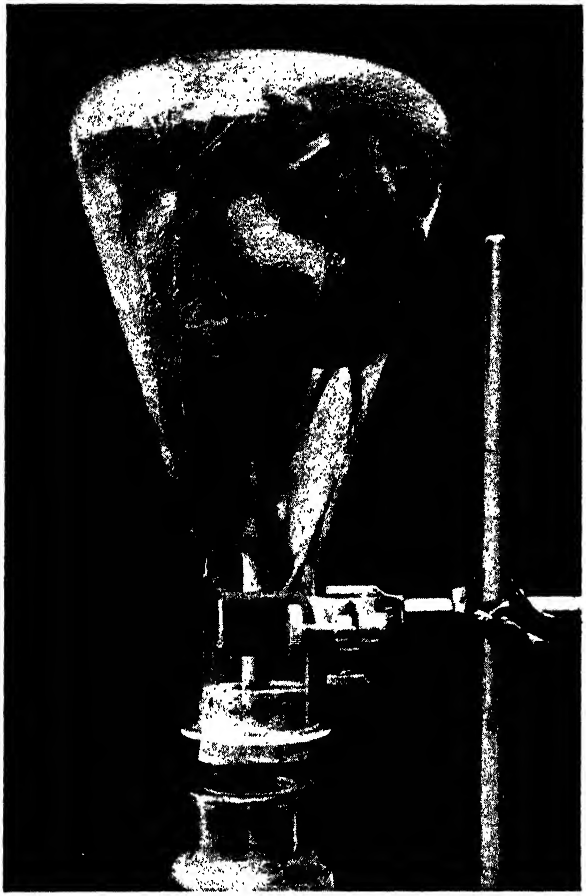


FIG. 77.—Demonstration of transpiration. A geranium shoot, held in an inverted flask by means of a split cork, has its lower end in a bottle of water. Moisture, evaporating from the leaves, condenses on the inside of the flask.

Water vapor is constantly being given off into the air from leaves; in fact, the chief value of the water that a plant absorbs from the soil is to replace that lost into the air. If this were not constantly replaced, the plant would wilt and eventually die. The giving off of water vapor from leaves is termed *transpiration*, but

it is essentially merely evaporation through stomata (Fig. 77). This water loss, always a danger to the plant, is unavoidable because the stomata must be kept open so that respiration and photosynthesis may go on.

The causes governing the upward movement of water in the plant have been extensively investigated, but as yet a thoroughly satisfactory solution of the problem has not been reached. It is apparent that an enormous amount of energy is required to cause water to rise to the height of tall trees. The source of this energy is still an uncertain matter. One of the most widely accepted theories seeks to explain the ascent of sap in terms of the lifting force of transpiration and the cohesive strength of water. Loss of water into the air from the mesophyll cells results in a concentration of their cell sap, and so water is drawn osmotically from the open ends of the veins. Transpiration exerts a tremendous pull on the innumerable threads of water in the xylem, and yet the particles of water in these minute threads seem to hold together. Physicists say that the cohesive strength of water is much greater than is commonly realized.

Photosynthesis.—When light falls upon a green plant, carbohydrates are made in cells containing chloroplasts. Carbohydrates are the products of photosynthesis and constitute the chief food of plants. The steps in their formation will be briefly considered.

Raw Materials.—The inorganic substances from which carbohydrates are made are water and carbon dioxide. Soil water, moving upward through the conducting system, passes from the ends of the veinlets to the mesophyll cells. Carbon dioxide from the air enters the leaf through its stomata, passes into the intercellular spaces, and becomes dissolved in the water that saturates the cell walls of the mesophyll tissue. Utilization of this gas in photosynthesis reduces its concentration in the intercellular spaces, and as a result it continues to enter the leaf by diffusion. The proportion of carbon dioxide in the atmosphere is only about 0.03 per cent, as compared with 78.2 per cent nitrogen, and 20.8 per cent oxygen.

The necessity of carbon dioxide to the manufacture of carbohydrates can be readily demonstrated by placing under a bell jar a vigorous potted plant and a small dish of caustic potash, a substance that absorbs carbon dioxide. Under these condi-

tions no carbohydrates are formed in the leaves. Other experiments have proved that green plants obtain from the air as carbon dioxide all the carbon that is used in constructing their organic compounds.

Agent.—Since photosynthesis is a function restricted not only to green plants but to cells containing chloroplasts, it is apparent that the presence of chlorophyll is essential to it. The agent in the manufacture of carbohydrates is the chloroplast—a specialized protoplasmic body containing chlorophyll. It should be noted that apparently it is not the green pigment itself, but the living matter in the chloroplast that carries on photosynthesis. It does this, however, only under the influence of the chlorophyll. Although the mesophyll of the leaves is the great center of photosynthetic activity, the process goes on in all green parts of the plant, as in the cortex of young stems.

Certain varieties of cultivated plants, such as geraniums, have variegated leaves, in which portions of the leaf fail to develop chlorophyll. When these plants are exposed to the light, carbohydrates are formed in the green parts of the leaves but not in the white parts, thus demonstrating that photosynthesis is dependent upon chlorophyll.

Energy.—Photosynthesis can proceed only in the presence of light. At night the process ceases. This is because the chloroplasts absorb radiant energy from the sunlight and employ it in the conversion of the raw materials to carbohydrates. As light passes through the leaf, the red rays are principally absorbed, but to some extent the blue and violet ones also. The other rays are not absorbed but are reflected, and this is why leaves appear yellowish green.

The necessity of light in photosynthesis can be shown by a simple experiment. A potted plant is kept in the dark for 24 hours. Then a piece of tin foil or opaque paper is fastened to one of its leaves in such a way that a portion of the leaf is covered from the light, but still has access to the air from below (Fig. 78). Upon testing for starch after the plant has been illuminated for several hours, it is found that none has formed in the shaded portion of the leaf.

Process.—In the presence of light, the chloroplasts have the power of combining carbon dioxide with water in such a way that a carbohydrate is formed and free oxygen is liberated.

The process of photosynthesis is represented by the following equation:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \rightarrow \underset{\text{Grape sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

This means that six molecules of carbon dioxide are combined with six molecules of water to produce one molecule of grape sugar

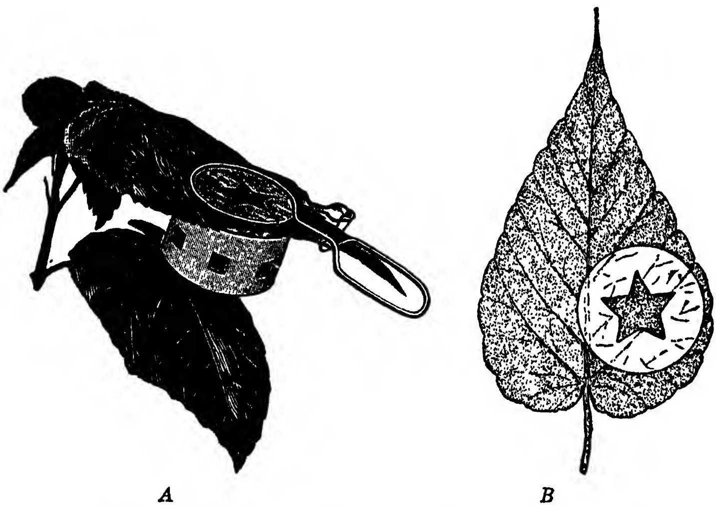


FIG. 78.—Experiment demonstrating the necessity of light in photosynthesis. *A*, a piece of tin foil in which a star-shaped hole has been cut is attached to the upper side of a leaf by a light screen that admits air to the lower side but excludes light; *B*, the same leaf treated with iodine after several hours' exposure to the light. The dark area indicates the presence of starch, which formed only where the leaf was illuminated. (*A, Courtesy of Bausch and Lomb Optical Co.*)

and six of free oxygen (each molecule of oxygen being composed of two atoms).[1] The primary product of photosynthesis is generally a simple carbohydrate known as *grape sugar*. Most of the free oxygen, liberated as a waste product, passes out of the leaf through the stomata, although some may be immediately used in respiration. The liberation of free oxygen during photo-

[1] Actually, the process of photosynthesis is not so simple as this, the equation representing only the end products of a series of intermediate reactions that are incompletely understood. It seems that the water and carbon dioxide are first decomposed by the chloroplast, their constituent atoms then being recombined, first into one or more simpler compounds, and finally into the carbohydrate.

synthesis may be observed by placing a jar of aquatic plants in sunlight (Fig. 79).

The energy absorbed from the sunlight and utilized by the chloroplasts in bringing about the union of carbon dioxide and water is stored in the carbohydrate just as energy is stored in a wound watch spring. This storage of energy is really the most significant phase of photosynthesis, for it is the potential energy contained in all foods that makes them capable of sustaining life.

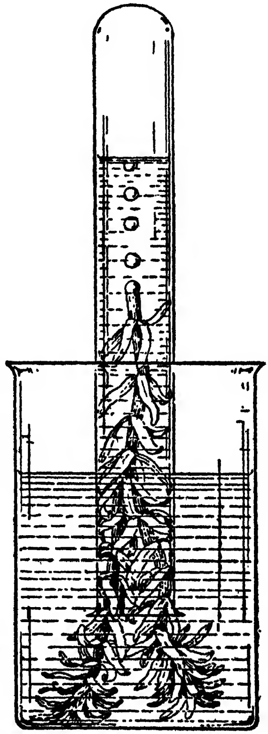


FIG. 79.—Experiment illustrating the release of oxygen in photosynthesis. Bubbles of oxygen are arising from the cut end of the stem of the water plant (*Elodea*) and are gradually displacing the water in the test tube. The apparatus is standing in sunlight.

Utilization of Food.—Sugar constitutes the chief food of plants and is the basis of all other organic substances formed in the plant body. After being made it may be immediately used by the leaf cells as a source of nourishment, or transported through the vascular system to other parts of the plant and there utilized. Ordinarily sugar is formed in a leaf more rapidly than it can be removed. The excess is then commonly changed to starch, an insoluble carbohydrate, which temporarily accumulates. At night, after photosynthesis has stopped, the starch is reconverted to sugar and transported in solution to other parts of the plant. It should be recalled that, for the most part, food is conducted through the phloem.

Food may be utilized by living cells in two ways: (1) as a source of energy (in respiration), thus enabling all vital activities to go on; (2) to form new protoplasm (in assimilation), thus resulting in growth.

Formation of Fats and Proteins.—These are more complex foods than carbohydrates. They are not made by photosynthesis directly from inorganic substances, but are transformation products derived from carbohydrates. Fats are compounds of

glycerin and fatty acids. They contain only carbon, hydrogen, and oxygen, the same elements that are present in carbohydrates, but here they are combined in a different way. In carbohydrates the hydrogen and oxygen are nearly always combined in the same proportion as they occur in water, but in fats the proportion of oxygen to hydrogen is much less. Fats usually occur in liquid form in plants, that is, as oils. They can be formed in any part of the plant where carbohydrates are present, not merely in green parts.

All organisms require some protein food because protoplasm itself is largely composed of proteins. Proteins are compounds of carbon, hydrogen, oxygen, and nitrogen, while most of them contain sulphur and some of them, phosphorus as well. They are elaborated carbohydrates to which new elements are added to form very complex compounds. The elements nitrogen, sulphur, and phosphorus enter the plant through its root system in the form of nitrates, sulphates, and phosphates, that is, as salts. Although nearly four-fifths of the air consists of free nitrogen, green plants are unable to utilize atmospheric nitrogen in the synthesis of proteins but must depend for their supply of nitrogen upon nitrates in the soil. The manufacture of proteins may take place at any time and in any living part of the plant, as it is not dependent upon either light or chlorophyll. In fact, it may occur in dependent plants, which get their carbohydrates directly from organic matter.

In addition to nitrogen, sulphur, and phosphorus, all green plants require four other elements that occur in the soil. These are potassium, calcium, magnesium, and iron. Minute traces of still other elements have been shown to be necessary also. None of these is used in protein synthesis but in other ways. Thus the ten principal elements that the plant must have in order to carry on its normal functions are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron. It should be realized that by far the greater part of the plant is composed of carbon, hydrogen, and oxygen, the elements obtained from carbon dioxide and water. All the seven other elements enter the plant from the soil in the form of salts.

Food Storage.—Food made by the plant and not immediately used accumulates in various parts of the body. This *reserve food,* as it is called, most frequently is stored in the form of

starch, although often sugars, fats, and proteins accumulate in varying amounts. It has already been seen that roots and seeds are common storage organs, while in many plants underground stems (rhizomes, tubers, or bulbs) serve as organs of food accumulation. All seeds contain reserve food, and because they contain little water, the food is highly concentrated. The amount of food stored in fleshy fruits, leaves, and ordinary stems is usually small. Reserve food represents nourishment to be used at some future time, either by the plant itself or by its offspring.

Digestion and Assimilation.—Before reserve food can be utilized it must undergo *digestion*, a process that may go on in any living part of the plant. The conversion of starch to sugar is an example of a digestive change. Digestion in organisms is accomplished by the action of substances called *enzymes*, of which there are many kinds. The commonest starch-digesting enzyme in plants is *diastase*. Reserve foods are mostly in an insoluble condition, and the process of digestion is merely a means of rendering foods soluble. This is necessary in order that they may pass by osmosis from cell to cell, and so that they may be eventually made into living matter. *Assimilation* is the transformation of digested food into protoplasm; it represents the final stage in constructive metabolism. Thus sugar itself and all the other kinds of foods made from sugar contribute to the actual organic substance of the plant. Growth can take place only through assimilation, which in turn is dependent upon food manufacture. Growth represents a predominance of the constructive phases of metabolism over the destructive ones.

Respiration.—Plants and animals are machines in the sense that they utilize energy in the performance of their functions. This energy is derived from the breaking down of complex organic substances within their own living bodies. If a green plant is kept in darkness so that photosynthesis cannot go on, its dry weight decreases because its protoplasm is slowly being destroyed. If a paramecium is kept in water containing no food, we can actually observe a gradual decrease in size until death finally ensues. All organisms are constantly consuming energy in carrying on their vital activities, and, as a consequence, food substances, as well as living matter itself, are always undergoing decomposition so that energy may be available. Unless renewed by the assimilation of additional food, there is a steady loss of

weight. Protoplasm must be built up because it is constantly being broken down. In other words, the constructive phases of metabolism must counterbalance the destructive ones if the life of an organism is to be maintained.

The ultimate source of all vital energy is the sunlight, for, as previously explained, solar energy is absorbed when carbohydrates are made by photosynthesis. This energy becomes stored in the food, and when food is assimilated it becomes incorporated in the protoplasm. All organic matter contains *potential energy*, which is energy at rest. To be utilized, this must be converted to *kinetic energy*, or energy in motion. Respiration is the means by which this is accomplished within the bodies of all plants and animals. Respiration is essentially an oxidation process, and this is why all organisms need oxygen in order to live. Most of the oxygen is absorbed from the air (of which it forms about one-fifth), entering the plant through the stomata and lenticels, but some also diffuses into the roots from the soil water in which it is dissolved. Oxygen is carried to all the living cells of the plant, diffusing mainly through the intercellular spaces. When oxygen combines with protoplasm, the latter breaks down into simpler products with an accompanying release of energy for use by the living machine. The chief products resulting from the decomposition of protoplasm through oxidation are water and carbon dioxide. The latter passes out of the plant through the stomata and lenticels into the air, and through the roots into the soil.

Respiration goes on at all times—in all living cells—in all plants and animals. It involves the absorption of oxygen and the liberation of carbon dioxide. The fundamental feature of respiration, however, is not this gas exchange but the destruction of organic matter within living cells in order that energy may be liberated for use in carrying on vital functions. Much misunderstanding often arises from failure to appreciate the significance of the gas exchanges that occur between green plants and the atmosphere. Therefore it should be understood that in photosynthesis, which proceeds only in the daytime, carbon dioxide is absorbed and oxygen is liberated, while in respiration, which goes on all the time, the gas exchange is just the reverse. At night only respiration is carried on, but in the daytime both processes take place simultaneously. Under favorable condi-

tions, however, when photosynthesis is active, there is much more oxygen given off than carbon dioxide. In fact, the latter may not even pass out of the plant but may be immediately utilized in the manufacture of sugar.

Photosynthesis and respiration may be contrasted as follows:

PHOTOSYNTHESIS	RESPIRATION
Organic matter is constructed	Organic matter is destroyed
H_2O and CO_2 are raw materials	H_2O and CO_2 are waste products
Oxygen is liberated	Oxygen is absorbed
Energy is stored	Energy is liberated
Occurs only in green tissues	Occurs in all living tissues
Occurs only in daytime	Occurs at all times

Irritability.—In order that the various metabolic functions of the plant may be carried on most advantageously, it is necessary that all the vegetative organs be brought into the most favorable relations with their environment. This is accomplished chiefly through the property of *irritability*, which is the power of responding to external influences, or *stimuli*. Irritability is an inherent property of protoplasm and so is common to all organisms. In general, plants react to stimuli much more slowly than do animals, and the mechanism of response is very different, since plants possess neither nerves nor muscles, and their cells are enclosed within rigid cell walls. Yet the response itself is just as definite in plants as in animals. Young parts of plants, such as root tips and elongating stems, are most sensitive to stimuli, but older parts often respond as well. Irritability in plants is manifested chiefly by the direction of growth and orientation that the various organs assume. Under ordinary conditions, the primary root grows downward, the main stem grows upward, and the branches and leaves are held in a more or less horizontal position. The chief stimuli that call forth these responses are *gravity*, *light*, and *moisture*.

Geotropism.—The action of gravity can be seen to advantage in seedlings. It is a well-known fact that, no matter in what position a seed is placed in the soil, when it sprouts, the primary root always grows downward, forcing its way through the soil, while the stem pushes upward toward the light and air. If a seedling is placed in a horizontal position, however, the root tip soon begins to turn downward again and the stem tip in the opposite direction (Figs. 80 and 81). The chief stimulus involved

in these reactions is gravity. It is evident that the root and stem respond to the same stimulus, but in an exactly contrary manner, the root growing toward the stimulus, the stem away

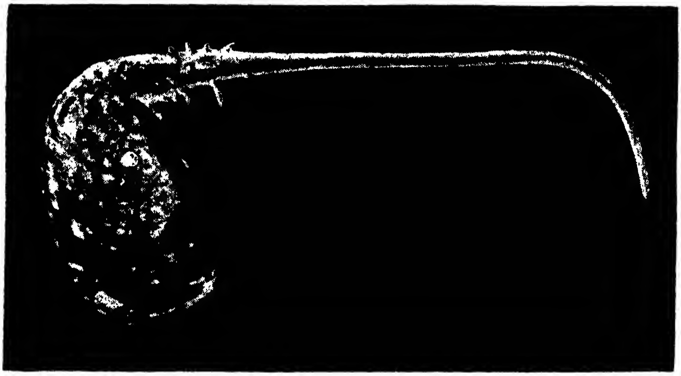


FIG. 80.—Young seedling of scarlet runner bean placed in a horizontal position and photographed 12 hours later. The root tip is growing downward in response to the stimulus of gravity.

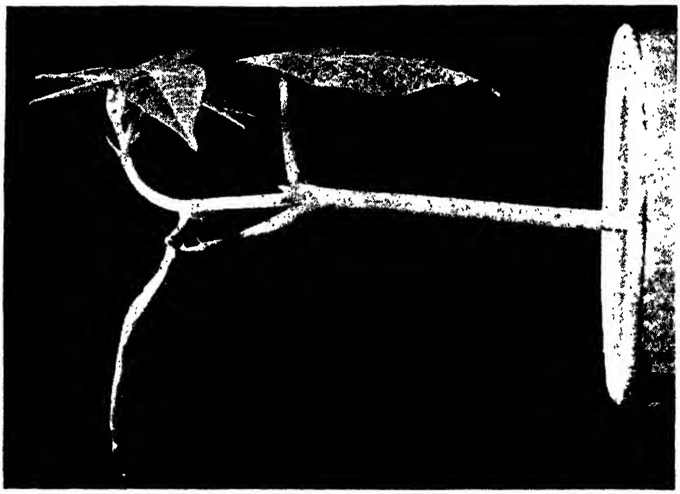


FIG. 81.—Older seedling of scarlet runner bean placed in a horizontal position and photographed 12 hours later. Note the response on the part of both the leaves and the stem.

from it. Leaves react to gravity also, generally becoming oriented in a horizontal plane, that is, at right angles to the direction in which the stimulus is acting (Fig. 81). Response to the stimulus of gravity is termed *geotropism.*

Mechanism of Response.—The mechanism of response is important to understand. When an organ is placed in a different position from that in which it has been growing, so that the stimulus of gravity acts in a new direction, it responds by a curvature. This is brought about by an unequal acceleration of growth on opposite sides of the organ Thus, in Fig. 81, the

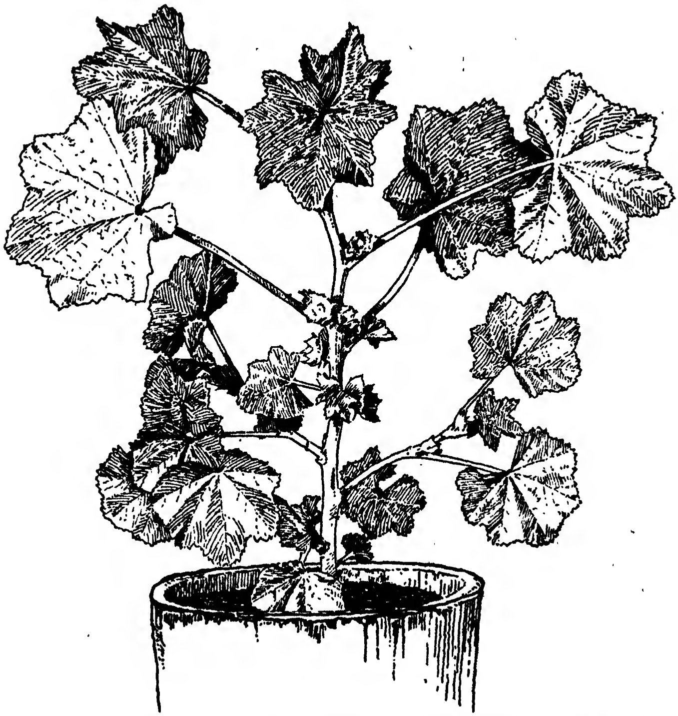


Fig. 82.—A young mallow plant (*Malva*) which has been exposed to one-sided illumination for several days. The flat faces of the leaf blades are held perpendicular to the light rays.

lower side of the stem is stimulated to grow faster, and in Fig. 80, the upper side of the root. The leaf is oriented by a growth curvature of the petiole, or by a twisting of the base of the blade itself. If a plant is placed in a horizontal position and slowly rotated so that the stimulus of gravity can act upon it with equal intensity from all sides, there is no reaction.

Phototropism.—The response of the shoot to light, called *phototropism,* is one of the most obvious expressions of irritability

in plants. Under ordinary conditions of illumination, most stems grow upward, while most leaves assume a horizontal position, their orientation manifestly being such that the rays of light strike the flat surface of the blade at right angles (Fig. 45). This permits the absorption of a maximum amount of solar energy for use in photosynthesis. With a change in the direction of the

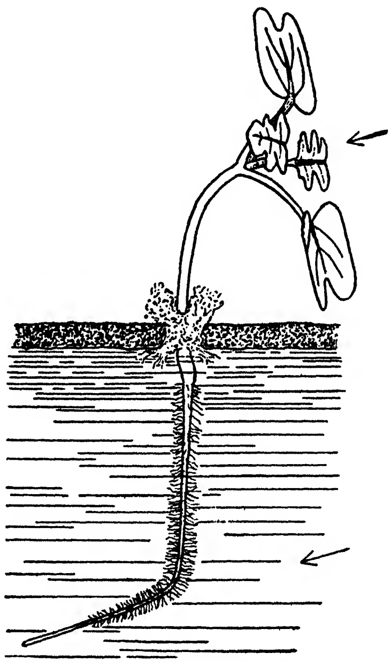


FIG. 83.—A mustard seedling growing with its root in water. The plant was first illuminated from all sides but later from only one side, as shown by direction of arrows. Note that the stem has bent toward the light and the root away from it, while the leaves have taken up a position at right angles to the light. (*After Noll.*)

light rays, the leaves assume a new position. This is apparent when a house plant is placed near a window, the stem tips tending to grow toward the source of light, while the leaves bend so that the blades are perpendicular to the direction from which the light is coming (Fig. 82). It is evident that the growth direction of the stem and the orientation of the leaves represent a definite response to the stimuli both of gravity and of light, and that the latter is the stronger influence. If a plant exposed to one-sided

illumination is slowly rotated, there is no response to light, as the intensity of the stimulus is then equalized.

Although roots ordinarily do not react to the stimulus of light, under appropriate conditions, and in some plants, they grow away from its source (Fig. 83).

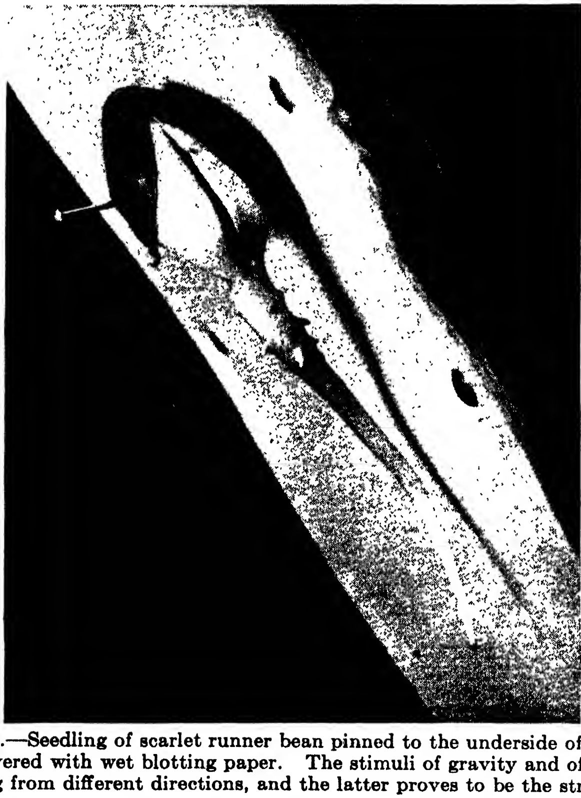


Fig. 84.—Seedling of scarlet runner bean pinned to the underside of a sloping board covered with wet blotting paper. The stimuli of gravity and of moisture are acting from different directions, and the latter proves to be the stronger.

Hydrotropism.—Although roots show little or no response to light, they are very sensitive to the stimulus of moisture, thus exhibiting *hydrotropism.* While this is not often apparent because gravity and moisture commonly act from the same direction, an experiment can readily be arranged in which the two stimuli act from different directions (Fig. 84). Then it is seen that the influence of moisture is stronger than that of gravity. It is obviously an advantage to the plant for its roots to grow from drier to more moist parts of the soil.

CHAPTER VIII

THE LOWER ANIMAL GROUPS

Although the simpler plants and animals resemble one another in many ways, bespeaking a common origin for all forms of life, the more complex members of each of the two organic kingdoms have become widely separated. In other words, the gulf between plants and animals becomes more and more pronounced as we pass from the lower to the higher organisms, until finally, except for basic features, they have little in common. Before beginning a study of the chief animal groups, it will be well to have in mind the main differences between plants and animals as evidenced especially by the more complex forms of life. In considering these differences, as given below, it should be realized that there are exceptions to every one of them.

PLANTS	ANIMALS
Cell walls present and tissues rigid	Cell walls absent and tissues soft
Tissues less highly differentiated	Tissues more highly differentiated
Organs external	Organs external and internal
Chlorophyll usually present	Chlorophyll absent
Food made by photosynthesis	Food obtained from external sources
Response to stimuli slow	Response to stimuli rapid
Growth occurring throughout life	Growth confined to early life
Stationary	Motile

The *animal kingdom* includes about 800,000 named and described species. Like the plant kingdom, it is divided into a number of major groups or *phyla*, the members of each having certain fundamental structural features in common. These animal groups represent different stages in complexity and will be considered in an ascending sequence. It must not be supposed, however, that every group is related by descent to the one below it, although in some cases this may be true. Each group should be regarded as standing for a different degree of progress from what was originally a more primitive condition. Each has reached a higher state of structural organization than those preceding it in the series.

PROTOZOA

The Protozoa, numbering over 15,000 species,[1] constitute the lowest and unquestionably the oldest group in the animal kingdom. All of them are unicellular and nearly all are microscopic in size. As a rule the cells are solitary, but in some cases they are arranged in colonies. Protozoans are found in fresh water, in the ocean, and in the soil, while some are parasites, living in the bodies of other organisms. Malaria, amoebic dysentery, and African sleeping sickness are human diseases caused by parasitic protozoans. In addition to the types discussed in Chaps. III and XIX, mention should be made of two large groups of marine protozoans whose cells secrete a shell around the protoplasm. In the one group (*Foraminifera*) the shell is composed of lime, in the other (*Radiolaria*) of silica. Enormous numbers of these simple creatures flourish in the ocean today and have since the beginning of the fossil record. Many of the deep-sea oozes are made up chiefly of their shells.

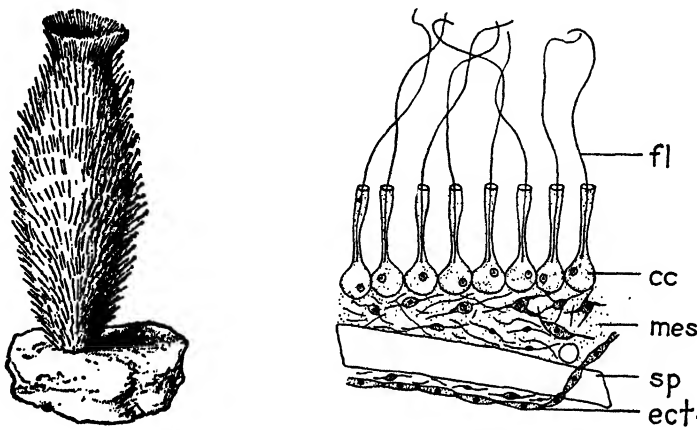
Fission is the prevailing method of reproduction among the protozoans, but in some cases spore formation occurs. Sexual reproduction is also common; conjugation may be temporary, as in *Paramecium*, or permanent, as in *Vorticella*. Structural complexity in this group has come about through the specialization of parts of single cells, rather than by the formation of tissues, as in the other groups. Animals that are not protozoans, *i.e.*, all multicellular animals, are called *metazoans*.

PORIFERA (SPONGES)

The Porifera, comprising the simplest group of metazoans, represent a transition between the protozoans and the other metazoans. They are mostly marine in distribution, being found in all seas, but a few sponges occur in fresh water. The group numbers about 3,000 species. Sponges are free swimming when young but later become permanently attached to objects in the water. The individuals may be solitary but are usually colonial. Sponges, most probably, have arisen from an ancient group of protozoans. They have had a long geologic history.

[1] Statements of number of species in this and the next two chapters refer to described species. The actual number, which includes undiscovered species, is very much greater in some phyla, as in protozoans, roundworms, and arthropods.

Structure.—The body of a simple sponge consists of a body wall surrounding a central cavity called the *cloaca* (Fig. 85*A*). It has a large terminal opening known as the *osculum*. Most simple sponges are urn-shaped and *radially symmetrical*, meaning that any plane which passes through the central axis of the body will cut it into two similar halves. In many sponges, especially colonial ones, the body has no definite symmetry. Colonial sponges commonly are cup-like, fan-shaped, or branched, but many are irregular. Some form incrustations on rocks.



A *B*

Fig. 85.—*A*, a simple sponge (*Sycon*), × 2; *B*, portion of cross section of *Grantia; cc*, collar cells of endoderm; *fl*, flagellum; *mes*, mesoglea; *sp*, portion of spicule; *ect*, ectoderm. (*A, from Minchin, in Lankester's "Treatise on Zoology"; B, after Shull, "Principles of Animal Biology."*)

The body wall of a sponge consists of only two layers of cells separated by a gelatinous, non-cellular *mesoglea.*[1] In the simplest sponges the body wall is not folded, but ordinarily it is folded in such a manner that a system of canals is formed. This may be either simple or complex. In all sponges the body wall is perforated by a great number of minute pores through which water enters. It then circulates through the canals, passes into the cloaca, and finally leaves the body by way of the osculum. The body wall of many sponges is supported by

[1] The outer and inner layers of a sponge seem not to correspond to the ectoderm and endoderm, respectively, of other metazoans, since in the sponge's development the position of the primary layers apparently becomes reversed.

numerous small elements called *spicules,* which may be composed of either lime or silica (Fig. 85*B*). These may be loosely scattered or more or less interwoven to form a firm framework. In other sponges a supporting network is present consisting of a fibrous organic material called *spongin.* A commercial or "bath sponge" is merely the dried skeleton of a sponge colony of the latter type.

Sponges have simple tissues, but there is little cooperation between the cells in the performance of their functions. Furthermore, no definite organs are present. Most of the cells in the body are of a simple type known as *epithelium.* The cells surrounding the minute openings in the body wall are contractile and close the pores in response to stimuli, thus functioning as simple muscle cells. It is of interest to note that these muscle cells are stimulated directly, no nerve cells being present. Water is drawn into the body and kept in circulation by means of ciliated *collar cells,* which line portions of the canals.

In the mesoglea are *spicule-forming cells, wandering amoeboid cells,* and *gametes* (Fig. 85*B*). Microscopic organisms and bits of dead organic matter, entering with the circulating water, are used as food. The cloaca is not a digestive cavity, but each cell lining a canal engulfs and digests its own food, as in the protozoans. Digested food may be transferred by osmosis from cell to cell. Respiration and excretion take place directly between the cells and the water in contact with them. The amoeboid cells may take up food, digest it, and transfer some of it to other cells. They also engulf waste particles and pass outside the body with them.

Reproduction.—Budding is a common method of asexual reproduction in sponges. In the solitary sponges the buds become separated, but in the colonial forms they remain attached, often growing together to such an extent that the lines of separation between the individuals become obliterated. The freshwater sponges form *gemmules*—small, protectively covered masses of cells that become detached from the colony in the late summer just before its death and produce new colonies the next spring.

Eggs and sperms, arising in the mesoglea, are generally produced by each individual, but since they ripen at different times, sponges are not self-fertilizing. Fertilization takes place in the canals. After the embryo has become a small spherical

mass of cells (a *blastula*), it develops cilia and escapes into the water as a free-swimming individual. Finally it settles down and completes its development.

COELENTERATA

The coelenterates have many features in common with the sponges but show an advance in several important ways. They

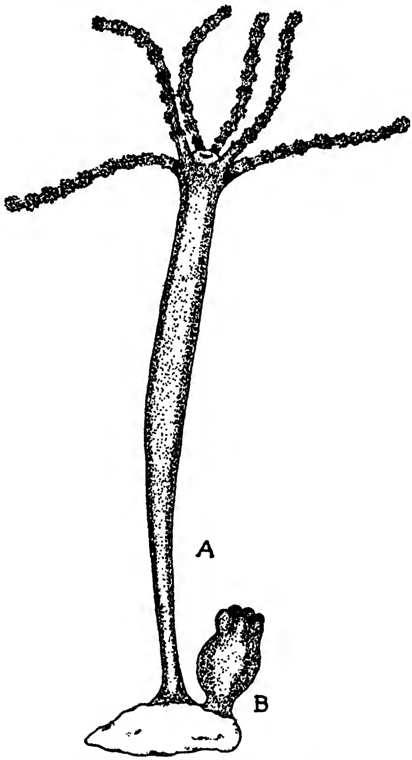


FIG. 86.—External view of a hydra in expanded (*A*) and contracted (*B*) conditions.

include the hydras, hydroids, jellyfishes, corals, sea anemones, etc. There are about 5,000 species, most of which are marine, but a few live in fresh water. Some of the coelenterates are attached, others are free swimming; some are solitary, others colonial.

The Hydra.—The hydra is one of the simplest of the coelenterates. There are two common species: the brown hydra (*Hydra fusca*) and the green hydra (*H. viridis*). Both are

found in fresh-water ponds and streams where they live attached to aquatic vegetation or to other objects in the water.

Structure.—The body of a hydra consists of a cylindrical hollow stalk attached at one end by a *basal disk*, and bearing five to ten slender finger-like *tentacles* at its unattached end (Fig. 86). The length of the brown hydra varies from 1/8 to

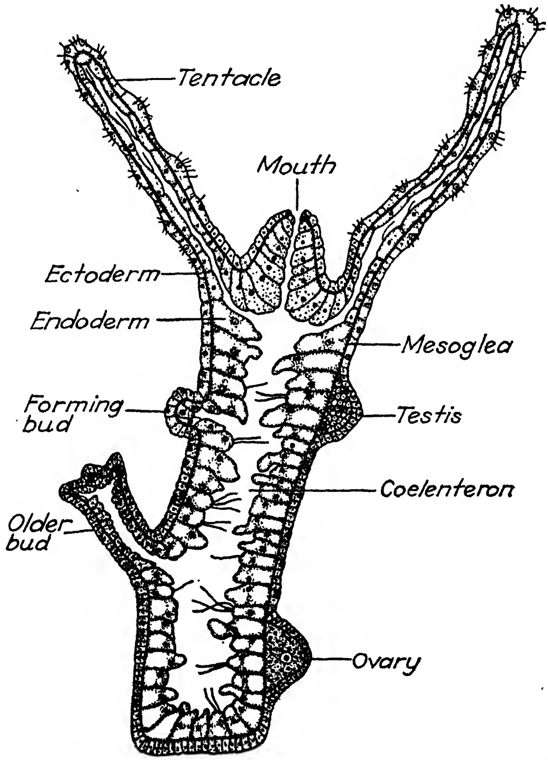


FIG. 87.—Longitudinal section of *Hydra*. (*Redrawn from Linville, Kelly, and Van Cleave, "General Zoology," Ginn and Company, after Parker, by permission.*)

3/4 inch, this difference being due to its power of contracting and expanding itself. The green hydra is somewhat smaller. Because the parts extend outward in all directions from a common center like the spokes in a wheel, the body of the hydra is said to exhibit *radial symmetry*. This is a feature of all coelenterates. Although attached, the animal can move from place to place by slowly gliding along on its basal disk. Locomotion may also

be accomplished by bending over, releasing the basal disk, and taking hold with it in a new position.

The tentacles surround a conical elevation called the *hypostome,* in the center of which is the *mouth.* This opens directly into a large internal cavity termed the *coelenteron* or *gastrovascular cavity,* which not only fills the stalk but extends out into the tentacles as well (Fig. 87). Surrounding the central cavity is a body wall consisting of two layers of cells, the outer layer being called the *ectoderm* and the inner one the *endoderm.* Between the ectoderm and endoderm is a thin, gelatinous, noncellular substance called the *mesoglea,* which in jellyfishes becomes very thick. Both layers are composed mainly of epithelial cells, most of which have the ability to contract and expand and so function also as simple muscle cells. There is also present in both ectoderm and endoderm a loose network of simple nerve cells, but these are not aggregated to form ganglia. The ectoderm contains peculiar stinging cells known as *nematocysts,* which are most numerous on the tentacles. Within each nematocyst is a coiled hollow thread containing a poison. The thread can be discharged into an animal coming in contact with the hydra. Nematocysts are used both for defence and for capturing prey.

The hydra feeds chiefly on smaller aquatic animals, which, coming in contact with the tentacles, are benumbed by the stinging cells and then conveyed by the tentacles to the mouth. Digestion takes place within the coelenteron, into which digestive fluids are secreted by numerous small glandular cells. The endoderm also contains large digestive cells, each of which has one or more cilia whose beating keeps the food in motion (Fig. 87). The digestive cells, by thrusting out pseudopodia, can engulf small solid particles of food, and so digestion occurs in two ways—both inside the coelenteron and within individual cells. The latter represents the primitive method characteristic of protozoans and sponges. The food digested within the gastrovascular cavity is absorbed by the cells of the endoderm, and some of it is passed by osmosis to the ectoderm. Indigestible matter remains in the cavity, being finally expelled through the mouth. Each cell of the body, being in contact with water, absorbs oxygen and gives off carbon dioxide and other waste products, thus carrying on respiration and excretion directly.

Reproduction.—The hydra reproduces both sexually and asexually. In asexual reproduction a *bud* may grow out from the stalk, develop a set of tentacles, and later become detached to form a new individual (Fig. 87). In the marine hydroids, animals related to the hydra, the new individuals produced by budding do not become separated, but remain permanently attached. As a result, a colony is formed, often consisting of thousands of individuals (Fig. 88). The hydra may also reproduce by fission, but this method occurs rarely (Fig. 154*A*).

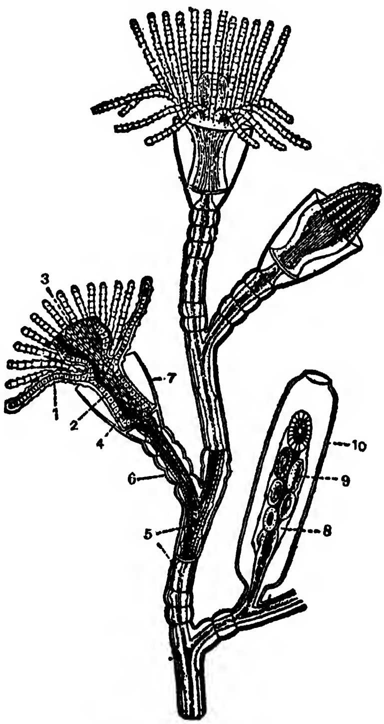


FIG. 88.—Portion of a colony of *Obelia*, a marine hydroid. 1, ectoderm; 2, endoderm; 3, mouth; 4, coelenteron; 5, stalk of colony; 6, 7, 10, enveloping sheath; 8, reproductive branch; 9, bud, which becomes detached and gives rise to a free-swimming individual (*medusa*). (*From Shipley and MacBride, "Zoology," Cambridge University Press, after Parker and Haswell, by permission.*)

Sexual reproduction in *Hydra* is a simple process. Sperms and eggs are borne on the same or on different individuals, depending on the species. The male organs, called *testes* or *spermaries*, arise in groups of two or three as conical elevations near the upper end of the stalk (Fig. 87). They are ectodermal in origin. Each testis produces a great many sperms, which are discharged into the water as free-swimming cells. The *ovary* is a knob-like organ formed in the ectoderm near the base of the stalk. It produces a single large egg. One of the sperms penetrates the ovary and fertilizes the egg. The zygote then gives rise to an embryo that undergoes part of its development within the ovary, but soon becomes free. After going into a short resting period, it then grows to the adult condition. In possessing definite sexual organs (testes and ovaries), the coelenterates show a marked advance over the sponges.

Other Coelenterates.—The hydroids are colonial, branching forms attached to objects in the ocean (Fig. 88). A colony consists of a stalk with numerous short branches, each of which bears a single *polyp*. Most of the polyps are somewhat similar

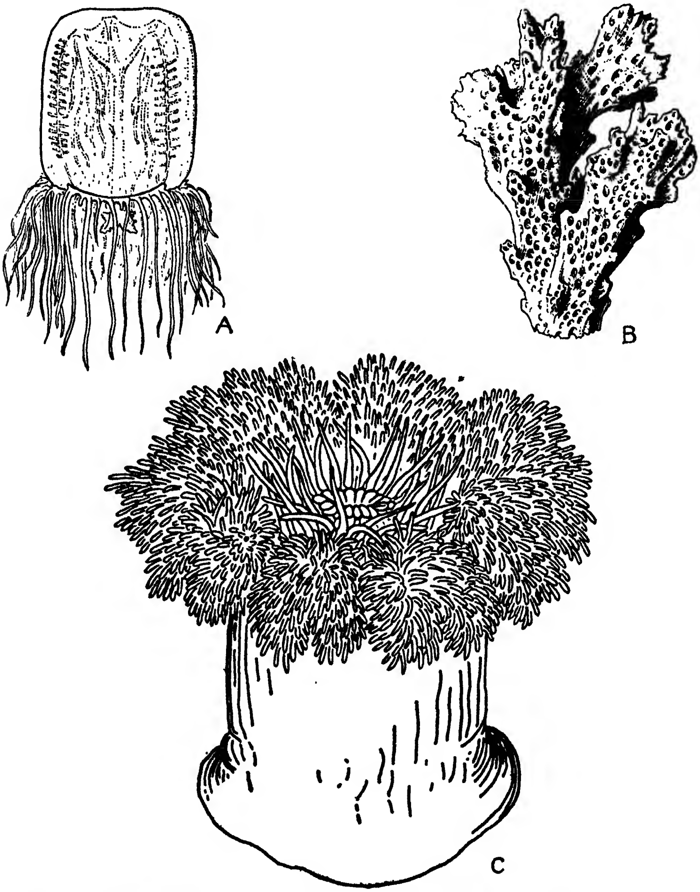


Fig. 89.—Representative coelenterates, natural size. *A*, the medusa stage of a hydrozoan jellyfish (*Polyorchis*); *B*, the skeleton of a coral; *C*, a sea anemone (*Metridium*). (*C, after Emerton.*)

to an individual hydra, but some are differentiated as reproductive branches. The latter, lacking a mouth and tentacles, are enclosed in a chitinous sheath that also covers the stalk and is expanded into a cup at the base of each nutritive polyp. The coelenteron is continuous throughout the stalk and branches but

does not extend into the tentacles. The reproductive branches produce buds that become detached from the colony and develop into free-swimming *medusae* (Fig. 89*A*). These are cup-shaped individuals with a marginal row of tentacles and a central mouth. The medusae bear sexual organs, the zygote giving rise to a polyp from which, by budding, a colony is developed. The alternate occurrence in the life history of an asexual and a sexual generation, of unlike form, is known as *metagenesis*.[1]

The true jellyfishes resemble medusae but are larger and more complex. They are solitary and free swimming. Some have a polyp stage in the life history. The sea anemones and corals are attached forms, the former being solitary and the latter colonial (Fig. 89*B* and *C*). In both groups the individual is a polyp in which the coelenteron is divided into chambers by thin partitions. A medusa stage is not present. In the corals a hard external framework of lime or of organic material is secreted by the individual animals in the colony. Many oceanic islands have been built up by the gradual accumulation of their remains.

Radial symmetry is a feature of all coelenterates. The body wall consists of but two layers of cells, constituting the ectoderm and endoderm, and for this reason coelenterates are said to be *diploblastic*. A single cavity is present (the coelenteron) having but one opening (the mouth). Digestion occurs mainly in this cavity but also in the individual cells lining it. The tissues are simple but are more highly differentiated than in sponges. A few simple organs are present, but there are no systems. The presence of stinging cells is characteristic. Like the sponges, the coelenterates are an ancient group and probably originated directly from protozoan ancestors.

PLATYHELMINTHES (FLATWORMS)

The flatworms are animals constructed on a higher plan of organization than the coelenterates but have some primitive features in common with them. They number about 6,000 species living in fresh water, in the ocean, and as parasites. A common fresh-water form is *Planaria* (Fig. 90), while two groups

[1] This phenomenon is also called "alternation of generations" but is not the same as alternation of generations in the plant kingdom, since in the hydroids both generations are diploid, the gametes being the only haploid cells in the life history (see p. 257).

of parasitic flatworms that live upon certain of the higher animals are the flukes and the tapeworms (Fig. 228). Most members of the group are solitary, but nearly all the tapeworms are colonial.

One of the most obvious differences between the coelenterates and the flatworms is the presence, in the latter, of *bilateral symmetry.* This means that only one plane, passing through its longitudinal axis, will divide the body into two approximately similar halves. A bilaterally symmetrical animal has an *anterior* (forward) and a *posterior* (rear) end, a *dorsal* (upper) and a *ventral* (lower) surface, and a *left* and a *right* side, but only the two sides are alike. As their name implies, flatworms are flattened dorsiventrally. Because of their type of symmetry, the flatworms exhibit a tendency to organize a head region that physiologically dominates the rest of the body. This tendency, known as *cephalization,* becomes more marked in most of the higher groups.

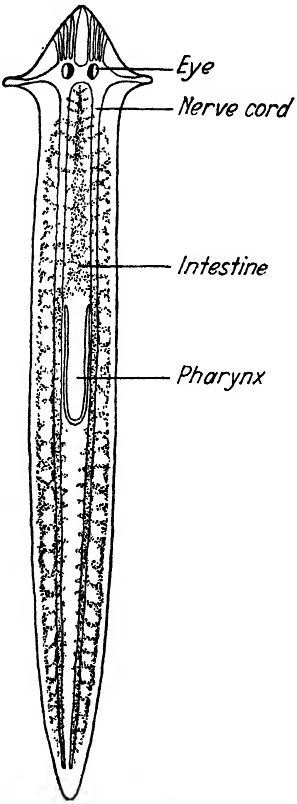


FIG. 90.—*Planaria dorotocephala,* a fresh-water flatworm, × 10. (*After Child.*)

The sponges and coelenterates are *diploblastic,* since only two layers of cells develop. In the flatworms an ectoderm and endoderm appear in early development, but soon another layer, called the *mesoderm,* is differentiated between them. Animals in which three primary cell layers are formed in the embryo are termed *triploblastic.* This feature continues in all subsequent groups. A primitive character retained by the flatworms is the presence of a single cavity (coelenteron) with just one opening (the mouth), but the cavity is usually highly branched. For example, in *Planaria* the mouth, located near the middle of the ventral surface, is connected by a tubular, extensible *pharynx* with an *intestine* that has three main branches, one

anterior and two posterior, all three with many lateral extensions (Fig. 90). This digestive tract corresponds to the gastrovascular cavity of the hydra, and in both cases waste products of digestion are expelled through the mouth.

A marked feature is exhibited by the flatworms in having, in addition to more complex tissues and organs, definite *systems*, as in all of the higher groups. Digestive,[1] nervous, excretory, muscular, and reproductive systems are present, but there is no circulatory or respiratory system. Digested food is carried directly to all parts of the body by the highly branched intestine, while respiration takes place directly through the surface of the body. Muscle fibers are developed as sets of tissues having no other function than contraction. The nervous system of *Planaria* consists of a bilobed *ganglion*, or mass of nerve cells, situated in the head region, and from it two lateral *longitudinal nerve cords* extend backward (Fig. 90). Many small nerves extend forward from the ganglion, rendering the head region particularly sensitive. Other nerves arise from the longitudinal nerve cords and extend transversely. The excretory system consists of a network of tubes extending throughout the body. Although reproduction in the flatworms may occur by transverse fission, this method is rare (Fig. 154*B*). Almost all flatworms possess both testes and ovaries on the same individual but as a rule are not self-fertilizing.

NEMATHELMINTHES (ROUNDWORMS)

The roundworms comprise over 4,000 species occurring in fresh and salt water, in the soil, and in the bodies of other animals. The body is mostly thread-like or cylindrical (Fig. 91). Many of the roundworms are parasitic. *Trichinella* causes a serious human disease known as *trichinosis*. It also attacks the pig, dog, rat, and mouse, being transmitted from one to another when the flesh of an infected animal is eaten. Man acquires the disease by eating improperly cooked pork containing encysted larvae. The hookworm (*Necator*) causes a human disease widespread throughout the southern part of the United States. The parasite lives in the intestine, entering the body either through the mouth or, more commonly, by burrowing through the soles of the feet.

[1] Tapeworms lack a digestive system.

Roundworms, like flatworms, are bilaterally symmetrical, triploblastic animals with complex body systems. But, instead of having a single cavity (coelenteron) with just one opening to the exterior, the body has two cavities—an outer *coelom*, surrounded by the body wall, and an inner *enteron*, or digestive tube. Moreover, the enteron has two openings, an anterior

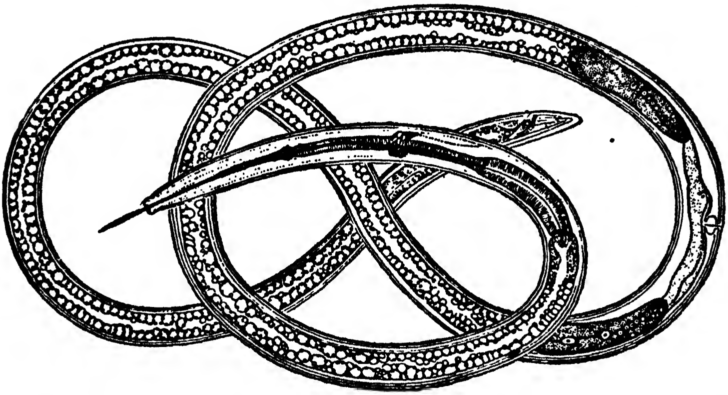


FIG. 91.—A nematode worm (*Xiphinema*) that lives on the roots of plants, greatly magnified. (*From Cobb, in Yearbook U. S. Department of Agriculture*, 1914.)

one, the *mouth*, and a posterior one, the *anus*. These two features persist in all subsequent groups.

ANNELIDA (SEGMENTED WORMS)

Coming now to the Annelida, appropriately designated as the "segmented worms," we find a group that makes a great advance over those which have been thus far considered. There are about 6,000 species of annelids occurring in fresh water, in the ocean, in soil, and as parasites. The earthworm is a familiar land form, the sandworm a representative marine annelid, while the leeches are well-known parasites.

The Earthworm.—Of the several common species of earthworms, *Lumbricus terrestris* is the one most often studied. It burrows in rich moist soil, coming to the surface only at night or after a heavy rain. Its general appearance and habits are familiar to every one.

General Features.—The elongated cylindrical body of *Lumbricus* is pointed at either end and slightly flattened on the lower surface. Its length varies from about 6 to 12 inches. Like

the two lower groups of worms that have been considered, the annelids exhibit *bilateral symmetry*. As previously explained, this means that only one plane, passing through its longitudinal axis, will cut the animal into two approximately similar halves.

The body of the earthworm consists of a linear series of ring-like segments called *metameres* or *somites*, all of which are essentially alike in form (Fig. 92). The segmentation of the body is very conspicuous, both externally and internally. At the anterior end of the body the *prostomium*, or upper lip, extends above and beyond the mouth and backward on the dorsal surface, intersecting the first metamere, which is thus not a complete ring. Located about one-third of the way from the anterior end is the *clitellum*, a thickened band-like portion of the body wall comprising six or seven metameres. It functions in reproduction.

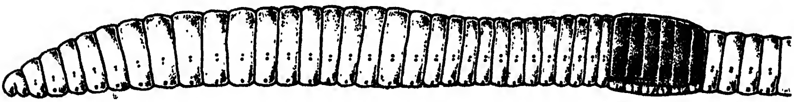


FIG. 92.—External view of the anterior portion of an earthworm as seen from the side, slightly enlarged. The thickened portion is the clitellum.

Each metamere, except the first and last, bears four pairs of short curved bristles called *setae*. They form four double rows—two lateral and two ventral ones. The setae assist in locomotion by sticking into the earth as the animal contracts.

The body wall of the earthworm is made up of several distinct layers in which muscle tissues predominate (Fig. 93). It surrounds a large fluid-filled cavity, the *coelom*. This is divided into compartments by transverse partitions called *septa*, each compartment corresponding to a metamere. Within the coelom and passing through the septa is the *enteron* or *alimentary canal*, a long digestive tube that extends the entire length of the body. It has an opening at either end, the anterior one being the *mouth* and the posterior one, situated in the last metamere, being the *anus*. In having two separate cavities—coelom and enteron—the body of the earthworm is built on the plan of a "tube within a tube" (Fig. 93). This important feature, also seen in the roundworms, is carried on into all the higher animal groups.

Digestive System.—The food of the earthworm consists of bits of dead vegetable and animal matter often mixed with soil.

It feeds at night, generally near the entrance to its burrow. In burrowing, the earthworm actually eats its way through the ground. Soil passes through the alimentary canal, the organic matter in it is digested, and the residue is deposited at the surface in the form of the familiar "castings."

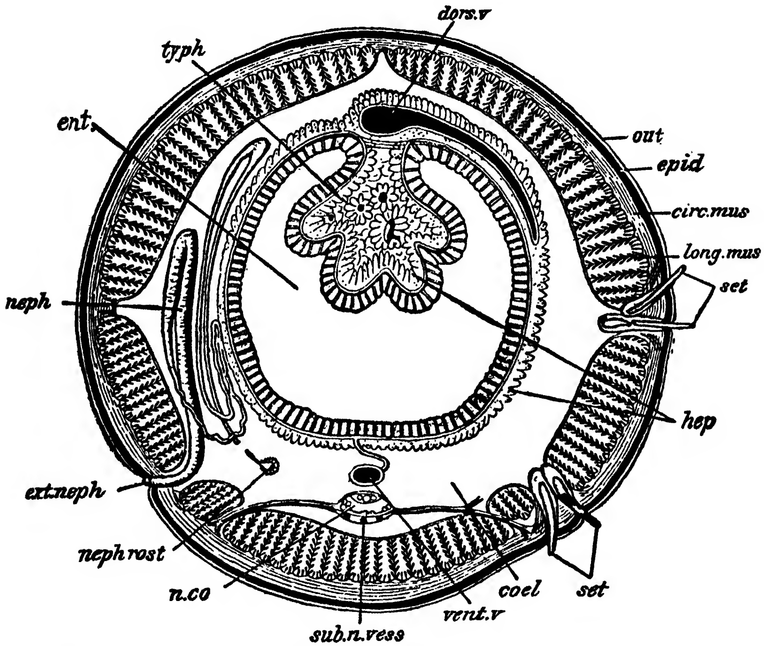


Fig. 93.—Cross section through the middle portion of the body of an earth worm. *cut*, cuticle; *epid*, epidermis; *circ. mus*, circular muscle fibers; *long mus*, longitudinal muscles; *set*, setae; *coel*, coelom; *dors. v*, dorsal blood vessel; *vent. v*, ventral blood vessel; *sub. n. vess*, subneural vessel; *n. co*, nerve cord; *typh*, typhlosole; *hep*, gland cells; *ent*, enteron; *neph*, nephridium; *ext. neph*, external opening of nephridium; *nephrost*, internal opening of nephridium. (*From Parker and Haswell, "Textbook of Zoology," The Macmillan Company, after Marshall and Hurst, by permission.*)

In addition to the mouth and anus, the digestive system comprises a number of specialized organs (Fig. 94). These are as follows: (1) the *pharynx*, a muscular sac that draws food through the mouth by suction; (2) the *esophagus*, a narrow tube leading backward from the pharynx; (3) the *crop*, a thin-walled enlargement of the digestive tube in which food is temporarily stored; (4) the *gizzard*, a thick-walled muscular organ where the food is ground up; (5) the *intestine*, a long straight tube constituting

most of the digestive system. It is in the intestine that the greatest part of digestion takes place. Cells contained in the inner lining of the intestinal wall secrete digestive enzymes into the enteron. Others absorb the food after it has been digested. The dorsal wall of the intestine is infolded so as to form a median ridge termed the *typhlosole*, the purpose of which is to increase the digestive and absorptive surface (Fig. 93). Following digestion, the soluble food passes by osmosis through the intestinal wall and is absorbed by the blood.

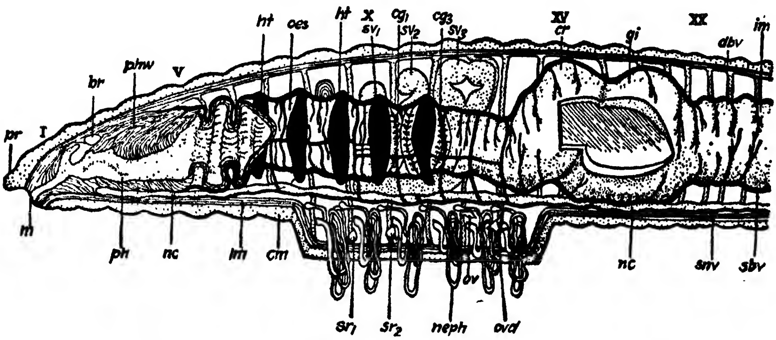


Fig. 94.—Dissection of the anterior end of the earthworm (*Lumbricus terrestris*), side view. I, V, X, XV, XX, number of metamere. Digestive system includes the mouth (*m*), overhung by the prostomium or upper lip (*pr*), pharynx (*ph*) with thick muscular wall (*phw*), esophagus (*oes*), digestive glands (cg_1 to cg_3), crop (*cr*), gizzard (*gi*), and intestine (*int*). Circulatory system includes aortic arches (*ht*), dorsal blood vessel (*dbv*), ventral blood vessel (*sbv*), subneural vessel (*snv*), and certain other vessels not here named. Excretory system includes nephridia (*neph*). Muscular system includes circular muscles (*cm*) and longitudinal muscles (*lm*). Nervous system includes suprapharyngeal ganglion (*br*), ventral nerve cord (*nc*), and other parts not shown. Female reproductive system includes ovary (*ov*), oviduct (*ovd*), and seminal receptacles (sr_1, sr_2). Male reproductive system includes seminal vesicles (sv_1 to sv_3), which enclose testes, not shown, and sperm ducts, not shown. (*From Shull, "Principles of Animal Biology," after Linville, Kelly, and Van Cleave.*)

Circulatory System.—In animals as complex as the earthworm, the transfer of respiratory gases and of digested food is not possible without the aid of a special circulatory system. The *blood* of the earthworm consists of a liquid *plasma* containing a large number of cells called *corpuscles*. A red pigment termed *hemoglobin* is dissolved in the plasma, the corpuscles being colorless. The blood is carried by a system of blood vessels and remains inside these at all times. Two principal vessels lie above and below the digestive tube; they are called, respectively, the *dorsal blood vessel* and the *ventral blood vessel*. These vessels extend

the length of the body and are connected near the anterior end by means of five pairs of *aortic arches* that pass around the esophagus (Fig. 94).

Blood flows forward through the dorsal vessel, down through the arches, and backward through the ventral vessel, this movement being caused by pulsations set up both in the dorsal blood vessel and in the aortic arches. These principal vessels give rise to many smaller branches that go to all parts of the body. The blood from the various parts of the body is returned to the dorsal vessel by means of a series of vessels encircling the body posteriorly—the *parietal vessels.* These arise from the *subneural vessel,* a long tube that lies beneath the ventral nerve cord and carries blood backward. In addition to the blood, a colorless fluid in the coelom, containing small amoeboid cells, also transports food to all parts of the body.

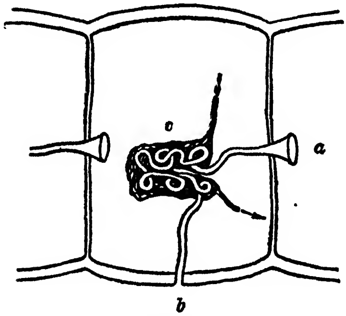


FIG. 95.—Diagram to show the main structural features of a nephridium of the earthworm, anterior end toward the right. *a,* internal opening of nephridium; *b,* external opening; *c,* network of capillaries about the coiled glandular portion. (*From Woodruff, "Foundations of Biology," The Macmillan Company, by permission.*)

The earthworm possesses no special aerating organs. The blood, carried by small vessels to the moist outer skin, takes up oxygen from the air and gives off carbon dioxide. By the secretion of mucus, the skin is kept moist so that this gas exchange can go on. The oxygen unites with the hemoglobin dissolved in the blood.

Excretory System.—Each metamere, except the first three and last one, has a pair of excretory organs called *nephridia.* These are long coiled tubes that collect metabolic waste products from the coelom, and directly from the blood vessels by osmosis, and convey them outside the body. Each nephridium has a ciliated funnel-like opening (*nephrostome*) in one metamere, passes through the septum into the next metamere behind, and then opens on the ventral surface of the body by means of a small pore (Figs. 94 and 95). Excretion in the earthworm is also effected by the activity of the small amoeboid cells present in the

coelomic fluid. These engulf solid waste particles and destroy them.

Nervous System.—The nervous system of the earthworm consists primarily of a *ventral nerve cord* extending the length of the body and located just beneath the ventral blood vessel (Fig. 96). It is really a fused double cord of nervous tissue. An enlargement of this cord, called a *ganglion,* occurs in every metamere except the first two. From the ganglia small *nerves* pass to the body wall and to the principal internal organs. The largest ganglion is the *suprapharyngeal ganglion,* a bilobed mass of nerve tissue situated in the third metamere just above the pharynx. From it sensory nerves pass to the prostomium. Below the pharynx in the fourth metamere is a slightly smaller ganglion, the *subpharyngeal ganglion.* These first two ganglia are connected with each other by means of a pair of nerve cords, known as the *circumpharyngeal connectives,* one of which passes around either side of the pharynx. Definite sense organs are lacking in the earthworm, but the skin is sensitive to touch and to light.

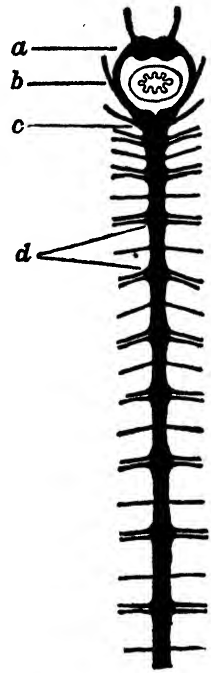


FIG. 96.—Diagram of dorsal view of the anterior portion of the nervous system of the earthworm. *a,* suprapharyngeal ganglion; *b,* circumpharyngeal connectives, *c,* subpharyngeal ganglion; *d,* ganglia of the ventral nerve cord with nerves emerging. (*From Woodruff, "Foundations of Biology," The Macmillan Company, by permission.*)

Reproductive System.—The earthworm is *hermaphroditic.* This means that both male and female organs occur on the same individual (Fig. 94). The former consist of two pairs of small *testes* located in the tenth and eleventh metameres and three pairs of large *seminal vesicles.* The sperms are produced in the testes and stored in the seminal vesicles, finally being carried to the surface of the body by means of a pair of *sperm ducts* with openings in the fifteenth metamere. The female organs comprise a pair of small *ovaries* in the thirteenth metamere. A pair of tubular *oviducts,* with external openings in the fourteenth metamere, carries the eggs to the surface of the body. There are also two

pairs of *seminal receptacles,* sacs in which sperms from another earthworm are received and stored.

Although the earthworm is hermaphroditic, it is not self-fertilizing. Two individuals come together with their anterior ends pointing in opposite directions and make an exchange of sperms, these passing from the seminal vesicles of the one worm to the seminal receptacles of the other. Later the clitellum secretes a gelatinous tube that is forced forward, carrying the eggs to the seminal receptacles. Then fertilization occurs. Thus the eggs of one earthworm are fertilized by the sperms of the other, and *vice versa.* The gelatinous tube, now containing

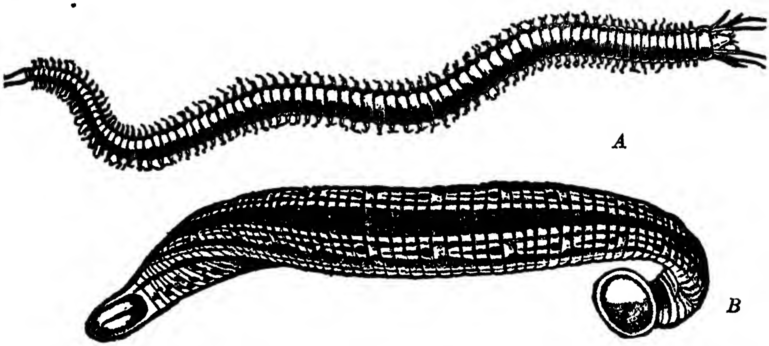


FIG. 97.—Segmented worms. *A*, the sandworm (*Nereis*), a marine annelid; *B*, a leech (*Hirudo*). *(From Shipley and MacBride, "Zoology," Cambridge University Press, A, after Oersted, by permission.)*

fertilized eggs, slips over the anterior end of the earthworm into the soil and forms a *cocoon,* within which the embryos develop.

Most of the marine annelids, upon hatching from the egg, pass through a *larval stage.* At first the larva, called a *trochophore,* is minute, disk-shaped, and unsegmented, swimming about by means of a circle of cilia. A similar stage appears in the development of certain other animal groups, as will be noted later.

Other Annelids.—Some of the marine annelids, such as the sandworm, are more highly developed than the earthworm in that a head is differentiated from the rest of the body (Fig. 97*A*). The head may bear jaws, eyes, tentacles, and other specialized organs. The setae may be in tuft-like masses borne on special locomotor appendages that also function as gills. The leeches lack setae and appendages, and have a sucker at either end of the

body (Fig. 97*B*). The anterior sucker contains the mouth. Most leeches are aquatic, some living in fresh water and others in the ocean. A few of them live on dead organic matter or on small animals, but most leeches are blood-sucking parasites, attacking larger animals.

The segmented worms, as their name implies, show a great advance over the lower animal groups in being metameric. They are triploblastic animals with bilateral symmetry, a large coelom, and an enteron having both an anterior and a posterior opening. All the systems of the body show a higher degree of development than in the preceding groups. Appendages are present in some cases, but are never jointed. Some of the annelids have a distinct head bearing sense organs, but as a rule all the metameres are alike and no body regions are present.

ECHINODERMATA

The echinoderms are a peculiar group of exclusively marine animals numbering about 5,000 species. They include the starfishes, sea urchins, brittle stars, sea cucumbers, sea lilies, etc. Their outstanding characters are the presence of radial symmetry and a high degree of structural development as compared with the preceding groups. Most of the echinoderms are motile but sluggish in their habits, while the sea lilies are attached.

The Starfish.—A number of species of starfishes are found on both the Atlantic and Pacific coasts of North America, as well as along other seacoasts. They live on the sea bottom rather close to shore, moving very slowly from place to place.

Structure.—The body of a typical starfish is composed of five *rays* extending outward from a central *disk* (Fig. 98). Embedded in the skin are calcareous plates forming a protective *exoskeleton.* Numerous spines are present, longer but less numerous on the lower, or *oral* surface, than on the upper, or *aboral* surface. The mouth is situated in a depression in the center of the oral surface of the disk. Extending outward from this depression into each ray is an *ambulacral groove* containing two or four rows of locomotor organs, the *tube feet* (Fig. 98*A*). On the aboral surface of the disk is a small central *anus* and a round perforated body known as the *sieve plate*, the latter lying between the bases of two of the rays. A small red *eyespot* is present at the tip of each ray.

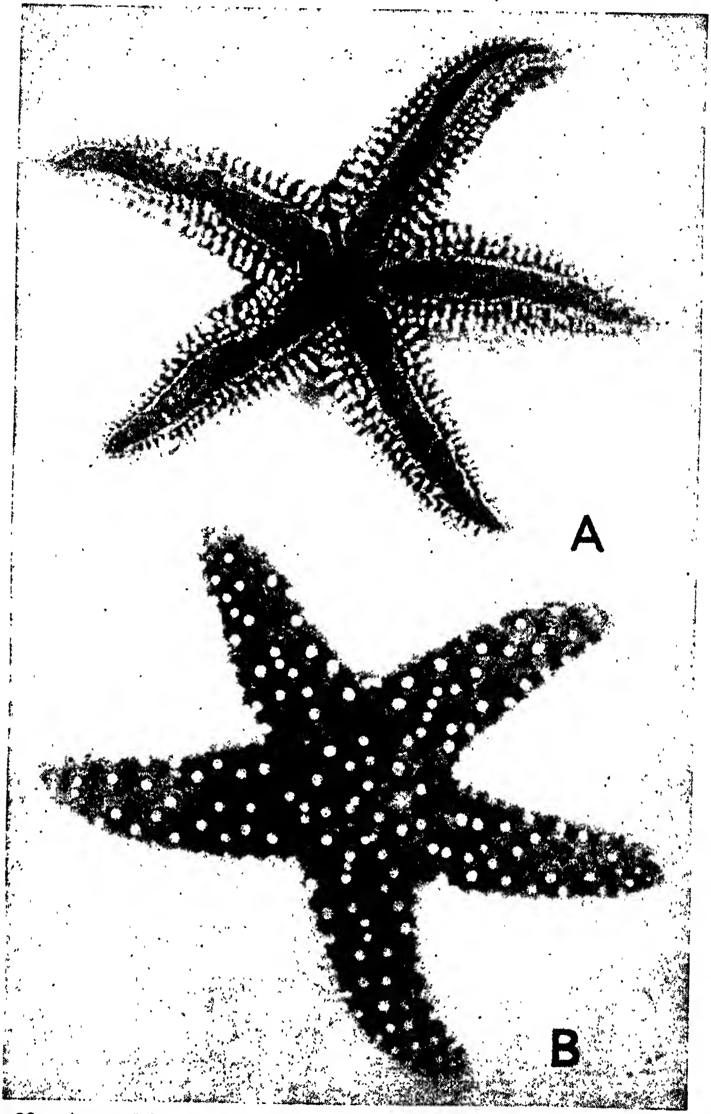


Fig. 98.—A starfish common along the southern California coast (*Pisaster capitatus*), natural size. *A*, oral view; *B*, aboral view.

The systems of the body show a high degree of development, the following being present: digestive, respiratory, nervous, water-vascular, and reproductive (Fig. 99). The alimentary canal is very short. The large *stomach*, situated in the central disk, sends a pair of short pouches into each ray. It is connected with the anus by means of a very short *intestine*. The anus is not functional. In each ray are a pair of large greenish *pyloric*

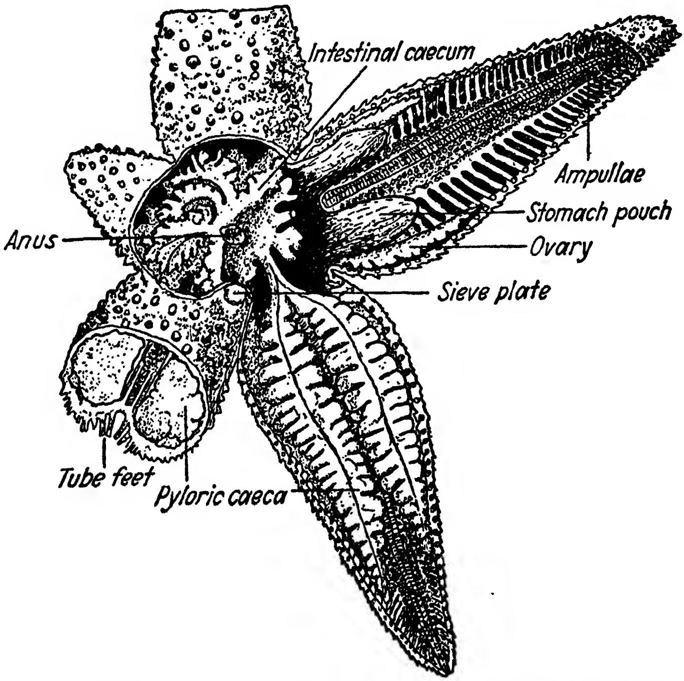


FIG. 99.—Dissection of the purple starfish (*Asterias vulgaris*), aboral view. (*After Linville, Kelly, and Van Cleave, "General Zoology," Ginn and Company, by permission.*)

caeca (digestive glands). The starfish possesses no blood vessels, but the coelom, which is large, is filled with a colorless fluid containing amoeboid cells, as in the earthworm. Oxygen and food are carried to the tissues by the coelomic fluid. Numerous short *gills* occur on the aboral surface of the body between the spines. Definite organs of excretion are lacking, but the wandering amoeboid cells collect waste matter and pass outside the body with it. The nervous system comprises a *circular nerve cord* in

the disk and a *radial nerve cord* in each ray; there are also many nerve cells lying in the skin.

A peculiarity of the starfish is the presence of a *water-vascular system* (Fig. 100). The sieve plate mentioned previously is connected, by means of a short tube called the *stone canal,* with a *ring canal* located in the central disk. From this a *radial canal* extends into each ray, and to it the numerous small *tube feet* are attached. The distal end of each tube foot forms a sucking disk, while at the other end is a small bulbous *ampulla.* Water enters the sieve plate, passes through the canal system, and enters the tube feet. By contraction of the ampullae, water is forced into the tube feet, which are thereby extended and fastened to the substratum. When the tube feet are contracted, water is forced back into the ampullae, and the animal moves forward. Locomotion by this method is very slow. The starfish feeds largely on clams and oysters, wrapping its rays about the victim, fastening its tube feet to the shell, and exerting a steady pull until it opens.

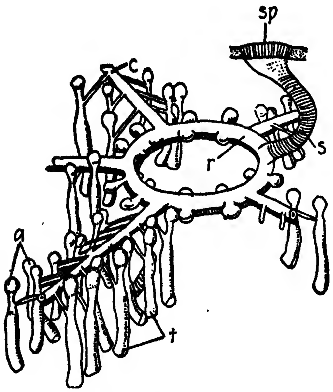


FIG. 100.—Water-vascular system of the starfish: *sp*, sieve plate; *s*, stone canal; *r*, ring canal; *c*, radial canal; *a*, ampullae; *t*, tube feet. (*After Hertwig-Kingsley, "Manual of Zoology," Henry Holt & Company, by permission.*)

Reproduction.—*Testes* and *ovaries* in the starfish are borne on different individuals. A pair of sexual organs occurs at the base of each ray and during the breeding season occupies the greater part of the coelom. Both the sperms and eggs are released into the water, and thus fertilization is external. The embryo develops at once, and while still in a very early stage of development (*blastula* stage) develops cilia and becomes free swimming. It is important to note that, as development proceeds, a bilaterally symmetrical larva is developed that remains ciliated but finally settles down and gradually passes into the adult condition. This free-swimming larval stage, characteristic of most echinoderms, resembles the trochophore larva of certain marine annelids and suggests that the group may have been derived from bilaterally symmetrical, worm-like ancestors.

Other Echinoderms.—The brittle stars differ from the starfishes in having slender rays sharply distinct from the disk and in lacking ambulacral grooves (Fig. 101*A*). Locomotion is

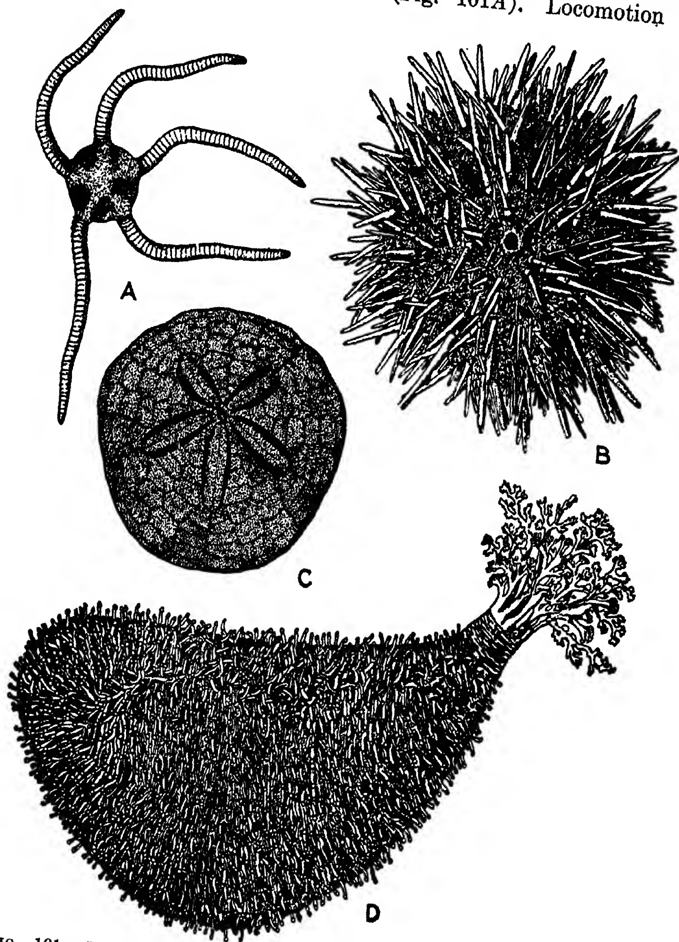


FIG. 101.—Representative echinoderms. *A*, a brittle star (*Ophioplocus*) × 2/3; *B*, a sea urchin (*Strongylocentrotus*), × 4/5; *C*, skeleton of sand dollar (*Dendraster*), × 3/4; *D*, a sea cucumber (*Thyone*), × 4/5. (*D*, after Coe.)

accomplished not by the tube feet but by rapid movement of the rays, the animal swimming through the water. The sea urchins and sand dollars are covered with spines but do not have

free rays (Fig. 101*B* and *C*). The sea urchins are globular and the sand dollars flat. There are no ambulacral grooves, but tube feet are present and borne by five pairs of radiating calcareous plates, between which lie five other pairs of plates. In the sea cucumbers the skin is soft and leathery, having small calcareous plates but no spines (Fig. 101*D*). The mouth, situated at one end of the elongated body, is surrounded by five branched tentacles that are used in feeding. The tube feet may be scattered over the whole surface of the body, confined to five double rows, or may be absent. The crinoids, or sea lilies, are mostly deep-sea animals, with five branched tentacles covered with tube feet, and are peculiar in being attached by means of a long stalk.

The echinoderms are an aberrant group of radially symmetrical animals probably derived from worm-like ancestors but not in the direct line of descent of any of the higher groups. In lacking a centralization of bodily activities, such as cephalized, bilaterally symmetrical animals possess, the echinoderms have emphasized an unprogressive type of organization. They are all triploblastic animals with a well developed coelom, the enteron, in most cases, having two openings. The group is characterized by three special features, *viz.*, (1) a spiny calcareous skin; (2) the occurrence of the organs in fives or in multiples of five; (3) a water-vascular system.

The echinoderms have left a fossil record extending far back into geologic history. The sea lilies were particularly abundant during certain ancient times.

CHAPTER IX

THE HIGHER INVERTEBRATES

The seven animal groups presented in the last chapter, together with several others of minor importance, may be conveniently referred to as the "lower invertebrates." In this chapter two additional groups, constituting the "higher invertebrates" are discussed, while the "vertebrates," the highest group in the animal kingdom, form the subject of the next chapter. *Vertebrates* are animals with a backbone; *invertebrates* those without one. Like *flowering* and *non-flowering plants*, these are inexact terms but convenient ones to use They are inexact because the groups to which they refer cannot be sharply set off from each other.

MOLLUSCA

Like the echinoderms, the mollusks are a non-metameric group of animals with a number of special features but differ from them in being bilaterally symmetrical and more highly developed in many ways. They include about 72,000 species living in fresh water, in the ocean, and on land, being represented by such forms as mussels, clams, oysters, snails, slugs, squids, cuttlefishes, and octopuses.

The Fresh-water Mussel.—The fresh-water mussels, of which hundreds of species are known, are common mollusks closely resembling the clams, all of which are marine. They inhabit the bottoms of streams, ponds, and lakes, where they lie partly buried in the sand or mud.

External Features.—Mussels are bivalve mollusks, the soft, unsegmented body being encased in a calcareous *shell* composed of two lateral *valves* (Fig. 102). These are united along their dorsal edges by an elastic *hinge ligament* that keeps the ventral edges open. Each valve bears a small rounded elevation called the *umbo*, around which may be seen the concentric *lines of growth*. The umbo is the oldest part of the valve. Projecting

ventrally from the space between the valves and directed downward is a large muscular *foot*, the organ of locomotion (Fig. 102). It permits the mussel to plow its way slowly through the sand or mud.

The calcareous shell consists of three distinct layers. The material composing it is secreted by a thin muscular sac which lies just inside it and encloses the internal organs. The sac is the *mantle*, and the space that it encloses is the *mantle cavity*. By the contraction of the two thick *adductor muscles*, one located at

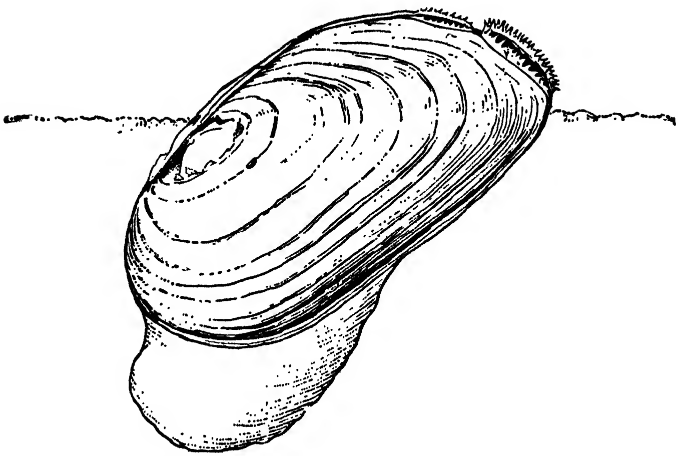


FIG. 102.—Living fresh-water mussel (*Unio complanatus*), one-half natural size. (*From Linville, Kelly, and Van Cleave, "General Zoology," Ginn and Company, by permission.*)

either end of the mantle cavity, the valves may be drawn together. At the posterior end of the body is a pair of short tubular siphons (Fig. 102).

Mantle Cavity.—Water enters the mantle cavity through the *ventral* or *incurrent siphon* and leaves through the *dorsal* or *excurrent siphon*, bringing food and oxygen into the body and removing waste materials from it. A pair of large plate-like *gills* occurs along the right and left sides of the mantle cavity (Fig. 103). They are covered with cilia whose beating draws in water through the ventral siphon. Passing over the gills, the water is deprived of its dissolved oxygen.

The food of the mussel consists of microscopic plants and animals, as well as bits of dead organic matter. Food is guided

to the *mouth* by two pairs of *labial palps* that surround it. The mouth, which is very small, is located between the anterior adductor muscle and the base of the foot (Fig. 103). It is connected with the *stomach* by means of a short *esophagus*. Surrounding the stomach is a large greenish *digestive gland*, which

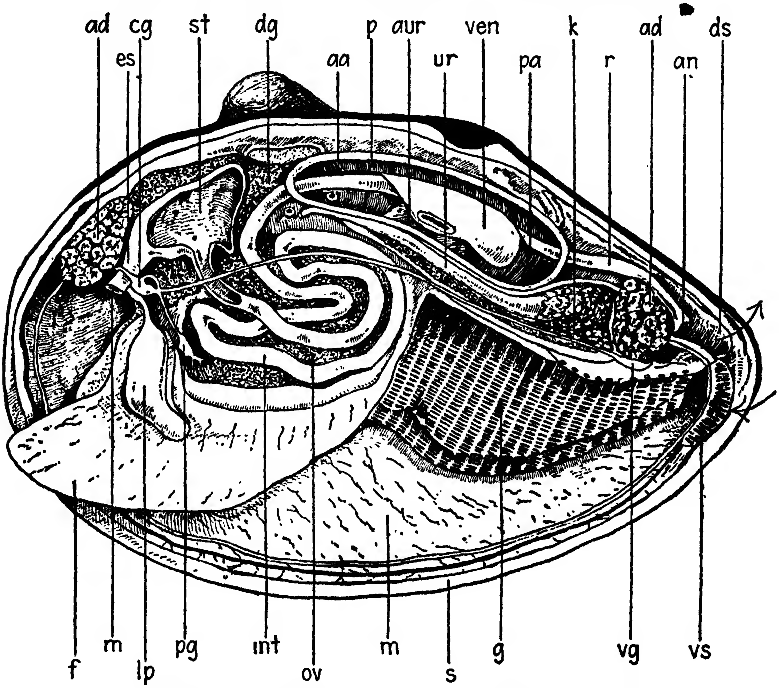


FIG. 103.—Dissection of fresh-water mussel. *ad*, adductor muscle; *f*, foot; *m*, mantle; *s*, shell; *ds*, dorsal siphon; *vs*, ventral siphon; *m*, mouth; *lp*, labial palps; *es*, esophagus; *st*, stomach; *dg*, digestive gland; *int*, intestine; *r*, rectum; *an*, anus; *p*, pericardium; *aur*, auricle; *ven*, ventricle; *aa*, anterior artery; *pa*, posterior artery; *g*, gills; *k*, kidney; *ur*, ureter; *cg*, cerebral ganglia; *pg*, pedal ganglia; *vg*, visceral ganglia; *ov*, ovary. (*Modified after Jewell model.*)

communicates with it by ducts. Leading from the stomach is a long, narrow, coiled *intestine*, which finally passes through the heart, without of course communicating with it. The *rectum* extends from the heart to the *anus*, the latter being located above the posterior adductor muscle. It communicates with the dorsal siphon.

The *heart*, enclosed by a delicate sac (the *pericardium*), consists of a median thick-walled *ventricle* and two lateral *auricles*. Blood coming from the gills and mantle folds, where it is.aerated,

first enters the auricles and then passes into the ventricle. This contracts, forcing the blood forward through the *anterior artery* and backward through the *posterior artery.* These give off many small branches with open ends from which the blood passes into a system of spaces called *sinuses;* these are divisions of the coelom. The blood now makes its way to a large vein that goes to the kidneys, where it gives up its nitrogenous wastes. Thence it goes to the gills, where it liberates carbon dioxide and takes up oxygen. Finally the blood returns to the heart through small vessels. The blood of mollusks consists of innumerable colorless *corpuscles* suspended in a liquid *plasma* in which is dissolved a bluish pigment called *hemocyanin.*

The excretory organs of the mussel comprise a pair of dark brown, spongy *kidneys* situated just beneath the pericardium and communicating with it by means of a short duct. Waste products are carried through a pair of short tubular *ureters* into the mantle cavity, finally passing out of the body through the dorsal siphon.

Nervous System.—The nervous system of the mussel is very primitive, a feature correlated with its sluggish life. It consists of three pairs of ganglia: (1) the *cerebral ganglia,* lying just behind the anterior adductor muscle and connected with each other by means of a slender nerve cord passing over the esophagus; (2) the *pedal ganglia,* located in the foot; (3) the *visceral ganglia,* situated at the base of the posterior adductor muscle (Fig. 103). Nerve cords connect the pedal ganglia with the others. The mussel has no organs of special sense, such as eyes or tentacles, but the edges of the mantle folds and the siphons are sensitive to stimuli.

Reproduction and Development.—As a rule, the sexes of fresh-water mussels are separate. The *testes* and *ovaries,* which are very similar in appearance, consist of a pair of cream-colored masses lying within the coils of the intestine. The sperms and eggs pass through a pair of ducts into the mantle cavity. The sperms leave the body of the male through the dorsal siphon and enter the ventral siphon of the female with the incoming water, fertilization and early embryonic development occurring in the gill region. Soon a peculiar larva known as a *glochidium* is formed (Fig. 104). After leaving the mother, the glochidia attach themselves to the gills or fins of fishes. The young mussel now leads a parasitic life as development proceeds, finally

leaving the fish and dropping to the bottom to assume an independent life. In many mollusks, such as oysters, a ciliated free-swimming larva is developed similar to that seen in the annelids and echinoderms.

Other Mollusks.—Clams are marine forms resembling mussels in having a bivalve shell, a hatchet-shaped foot adapted for digging, and a pair of siphons. Oysters and scallops are marine bivalves that lack a foot and siphons and have only one adductor muscle. Oysters lie flat on the sea bottom, their two valves being unequal in size. Scallops swim through the water by rapidly opening and closing their valves. The mantle folds bear numerous slender tentacles and a row of eyes. None of the bivalve mollusks has a head.

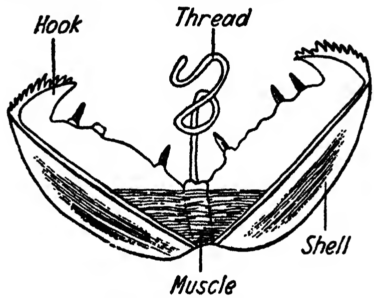


FIG. 104.—Larva of mussel (*glochidium*), much enlarged. (*After Balfour.*)

The snails and their relatives usually have a spiral shell consisting of only one valve (Fig. 105*A*), but in some cases a shell is lacking. A distinct head, bearing eyes and tentacles, is present. The foot is broad and flat and is used for crawling. The bilateral symmetry that characterizes other mollusks has become obscured in the case of the snails and their relatives, most of the body, except the head and foot, being asymmetrical owing to the necessity of accommodating it within a spiral shell. The chambered nautilus, a rare deep-sea animal of the South Pacific Ocean, has a coiled shell divided into compartments, each representing a space in which the animal formerly lived. About 40 tentacles form a circle around the mouth. In the related squids, cuttlefishes, and octopuses, the shell is either absent, or internal and reduced to a small flat plate. Here the foot is divided into either 8 or 10 tentacles, which are used in swimming or for capturing prey (Fig. 105*B*). The mantle forms a tubular sac that encloses the entire body except the head. Two large eyes are present. In the squids and cuttlefishes a pair of lateral folds of the mantle forms fins, which assist in swimming.

All mollusks have a soft non-metameric body, which is generally encased in a hard calcareous shell. All of them have a

characteristic organ, the foot, which is variously modified, and in most cases a mantle is present. Mollusks are bilaterally symmetrical and triploblastic. A distinct head may or may not occur. The digestive system is well developed and has both mouth and anus, but the coelom is small. Mollusks make their

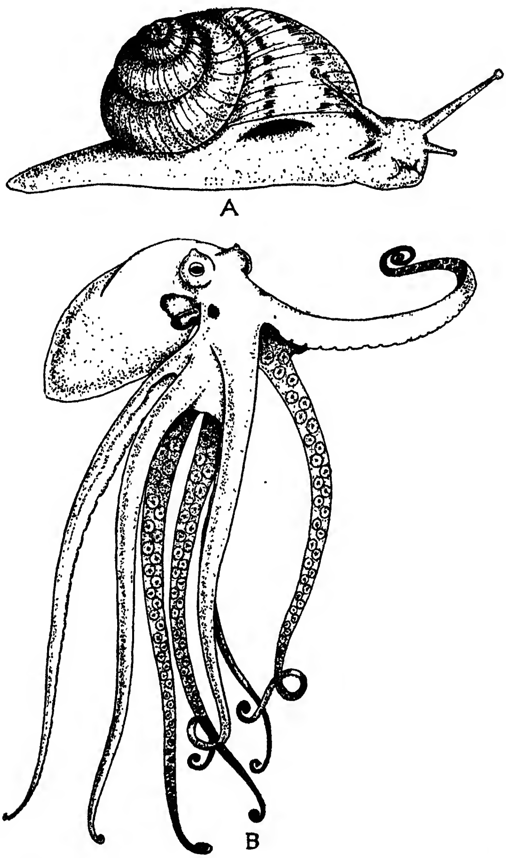


FIG. 105.—Representative mollusks. *A*, a land snail (*Helix*), natural size; *B*, a small octopus (*Polypus*), one-half natural size.

appearance as fossils in very ancient rocks and have remained abundant throughout geologic history. Although their relationships to other groups is not obvious, the fact that the larvae of many mollusks are ciliated and free swimming suggests a remote affinity with the annelids and echinoderms.

ARTHROPODA

Numerically the arthropods surpass all the other animal groups combined, there being over 640,000 species. In other words, there are about four times as many arthropods as all the other known species of animals taken together! Although having few features in common with the echinoderms and mollusks, they are

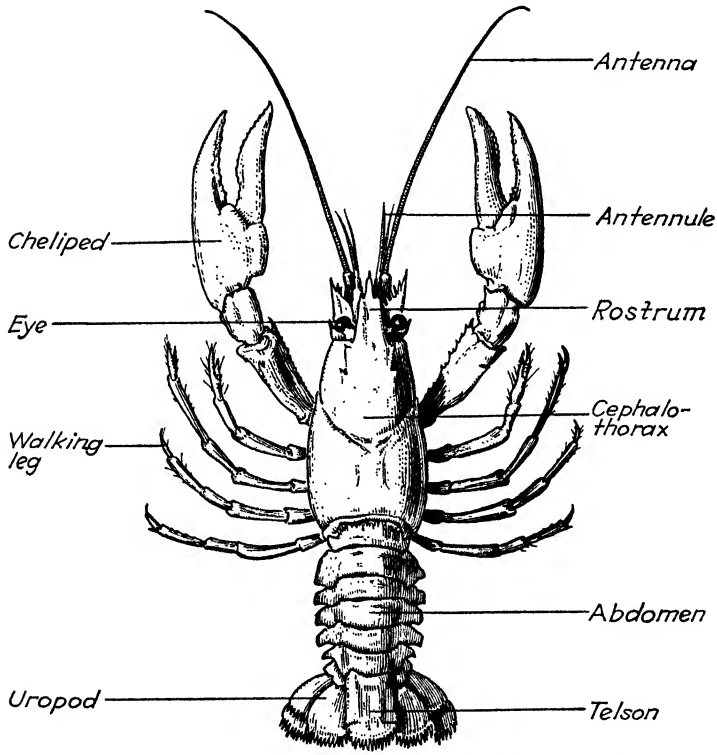


FIG. 106.—Dorsal view of western crayfish (*Astacus trowbridgii*), one-half natural size.

closely related to the segmented worms, showing striking evidence of having been derived from them in the distant past. The arthropods are more highly developed than the annelids in a number of important respects, notably in the possession of jointed appendages, the name arthropod meaning "jointed foot." The lowest class are almost exclusively aquatic, but nearly all the other members of the group live on land. The chief classes are

the crustaceans, myriapods, insects, and arachnids. These will be considered separately.

The Crayfish.—The crayfishes, including a number of species, are fresh-water crustaceans very similar to the lobsters, which are larger and live in the sea. They crawl on the bottom of ponds and streams, concealing themselves beneath stones and logs. Some kinds live in moist meadows where they make burrows in the ground.

External Features.—The body of the crayfish is composed of a *head, thorax,* and *abdomen,* but the first two regions are fused to form a single division, the *cephalothorax* (Fig. 106). Each of these is made up of metameres, the head of five, the thorax of eight, and the abdomen of seven. A firm outer covering composed of *chitin,* a horny organic material, and impregnated with lime, is present on all parts of the body except the ventral surface of the abdomen. This *exoskeleton* not only protects the internal organs but serves as a place for the attachment of muscles. It is thin and flexible where joints occur, thus permitting movement to take place. The exoskeleton is shed periodically so that growth can occur. A distinct plate, called the *carapace,* covers the top and sides of the cephalothorax, its presence obscuring the metamerism in this region. The *cervical groove,* a depression extending across the carapace, marks the line of union between the head and thorax. Anteriorly the carapace is prolonged into a hard beak, the *rostrum,* on either side of which is a large stalked *compound eye* at the end of a movable stalk. Each eye is composed of about 2,500 *facets* (simple eyes), which form separate images.

The Appendages.—Of the 20 metameres in the body of the crayfish, all but the last one bear a pair of jointed appendages. The most significant fact about them is that, in spite of their diversity, they are all constructed according to the same fundamental pattern and so are said to be *homologous.* One of the *swimmerets* from the third, fourth, or fifth abdominal segment shows the structural plan common to all the appendages, *viz.,* a basal portion (*protopodite*) giving rise to an inner branch (*endopodite*) and an outer branch (*exopodite*). In the embryo all the appendages are two-branched and otherwise similar, but later they become modified in accordance with the functions that they are to perform. Frequently the exopodite is lacking,

Body region	Metamere	Appendages	Function
Head	1	Antennules	Sensory
	2	Antennae	Sensory
	3	Mandibles	Feeding
	4	1st maxillae	Feeding
	5	2d maxillae	Feeding
Thorax	6	1st maxillipeds	Feeding
	7	2d maxillipeds	Feeding
	8	3d maxillipeds	Feeding
	9	Chelipeds	Grasping
	10	1st walking legs	Walking
	11	2d walking legs	Walking
	12	3d walking legs	Walking
	13	4th walking legs	Walking
Abdomen	14	1st swimmerets	Copulatory in male Reduced in female
	15	2d swimmerets	Copulatory in male Attachment of eggs and young in female
	16	3d swimmerets	Generalized in male Attachment of eggs and young in female
	17	4th swimmerets	Generalized in male Attachment of eggs and young in female
	18	5th swimmerets	Generalized in male Attachment of eggs and young in female
	19	Uropods	Swimming
	20	Absent	

as in the walking legs. The appendages of the nineteenth metamere (the *uropods*), together with the *telson*, or last metamere, form a flat, fan-shaped tail effectively used in swimming backward. The names of the appendages, their location, and their functions are given in the above table.

Internal Anatomy.—The digestive system of the crayfish consists of a *mouth*, *esophagus*, *stomach*, *intestine*, *anus*, and a pair of large *digestive glands* (Fig. 107). The circulatory system comprises principally a *heart* and seven main *arteries*. The blood is composed of a plasma containing numerous amoeboid cells; its function is to transport both food and oxygen to the tissues and

to remove metabolic waste products from them. The crayfish has colorless blood, but that of most crustaceans is blue, as in the mollusks. The blood leaves the heart through the arteries, flows into smaller vessels with open ends, and from these passes out into *sinuses* or spaces that surround the internal organs. The blood now goes to a large ventral sinus and then by veins to the gills, from which, after being aerated, it returns to the heart, entering through three pairs of lateral openings.

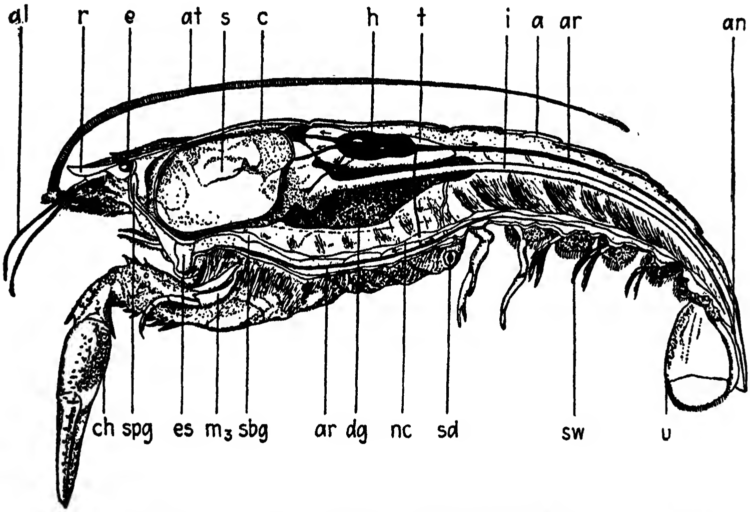


FIG. 107.—Dissection of male crayfish (*Cambarus limosus*), × 1. *al*, antennule; *at*, antenna; *r*, rostrum; *e*, compound eye; *c*, cephalothorax; *a*, abdomen; *ch*, cheliped; m_3, third maxilliped; *es*, esophagus; *s*, stomach; *dg*, digestive gland; *i*, intestine; *an*, anus; *h*, heart; *ar*, artery; *spg*, supra-esophageal ganglion; *sbg*, subesophageal ganglion; *nc*, nerve cord; *t*, testis; *sd*, external opening of sperm duct; *sw*, swimmeret; *u*, uropod. (*After Linville, Kelly, and Van Cleave, "General Zoology," Ginn and Company, by permission.*)

Two or three rows of plume-like *gills*, located beneath the carapace on each side of the cephalothorax, constitute the respiratory organs, and a pair of *green glands*, situated in the ventral part of the head, comprises the organs of excretion. Their external openings occur on the basal segments of the antennae. The general construction of the nervous system is similar to that of the earthworm. A *ventral nerve cord* extends the length of the body beneath the alimentary canal. Seven *ganglia* occur in the cephalothorax, where the nerve cord is double, and six in the abdomen, where it is single. Nerves pass

from all the ganglia to various parts of the body. The first ganglion, lying above the esophagus, is connected by a pair of slender cords with the second one, located beneath the esophagus. Each of these represents several ganglia that have fused together.

Reproduction.—The sexual organs of the crayfish are always borne on separate individuals. There is only one *testis* or *ovary* present, as the case may be, but each is connected, by means of a pair of ducts, to a pore situated at the base of each of the fourth walking legs in the male, the second in the female. The sperms are deposited in a shallow cup, the *annulus*, which occurs in the

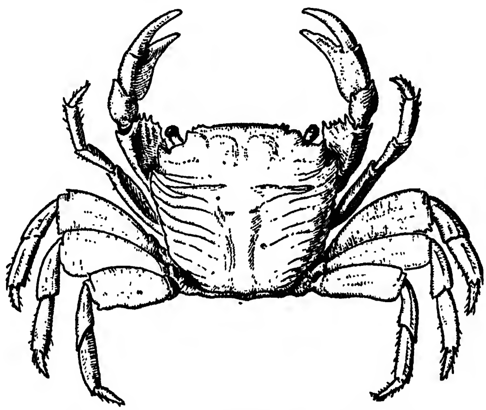


FIG. 108.—Striped shore crab (*Pachygrapsus crassipes*), three-quarters natural size. As in other crabs, the abdomen is permanently folded under the cephalothorax.

female between the fourth pair of walking legs, and here they are stored for a long time. The eggs are fertilized when laid and then become fastened to the swimmerets as development proceeds. After hatching, the young remain attached to the swimmerets until able to care for themselves.

Other Crustaceans.—The crustaceans are mainly an aquatic group, numbering about 18,000 species and including the crayfishes, lobsters, crabs, shrimps, prawns, barnacles, sow bugs, etc. (Fig. 108). Most crustaceans live in the ocean, some in fresh water, and a few on land. Some have adopted a life of partial or complete parasitism. The barnacles live attached to various objects in the sea, such as rocks, posts, and ship bottoms, and as adults show little resemblance to other crustaceans. They have a calcareous shell consisting of several pieces.

Crabs are peculiar in having the abdomen permanently folded under the cephalothorax, which is commonly broader than long.

The head, thorax, and abdomen, into which the body of a crustacean is divided, may be entirely separate, or the head and thorax may be fused to form a cephalothorax. In most cases the head bears two pairs of antennae and a pair of compound eyes. The number of metameres is rarely more than twenty, and typically each one bears a pair of branched, jointed appendages. The exoskeleton contains both chitin and lime. Except in the lowest forms, the respiratory organs consist of a pair of gills, and the excretory organs of a pair of green glands.

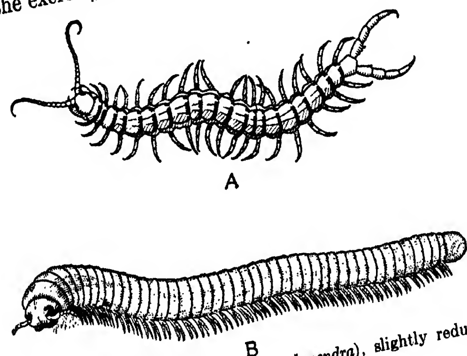


Fig. 109.—Myriapods. *A*, a centipede (*Scolopendra*), slightly reduced; *B*, a millipede (*Spirobolus*), natural size.

The most ancient and most primitive arthropods were the *trilobites*, a group of crustaceans (Fig. 247). These forms were very abundant during early geologic times, but have been extinct for many millions of years.

The Myriapods.—The myriapods are a terrestrial group of about 2,000 species, comprising the millipedes and centipedes (Fig. 109). These forms are more worm-like than the three other classes of arthropods, having a head but no differentiation between thorax and abdomen. Millipedes are mostly cylindrical in shape, every metamere back of the head (except the first one) bearing two pairs of short jointed legs. They are sluggish in their habits and most of them feed entirely upon vegetable matter. Centipedes are flattened dorsiventrally, and each metamere back of the head (except the last two) bears a single

pair of jointed legs. Centipedes are very active creatures, capturing worms, insects, and other small animals. Both millipedes and centipedes have only one pair of antennae, and most of them have two simple eyes.[1] Their respiratory and excretory organs are similar to those of insects.

The Grasshopper.—The grasshoppers, or locusts, are widely distributed insects comprising a large number of species, any one of which will serve to illustrate the general features of insect morphology. They live in grassy places and feed upon vegeta-

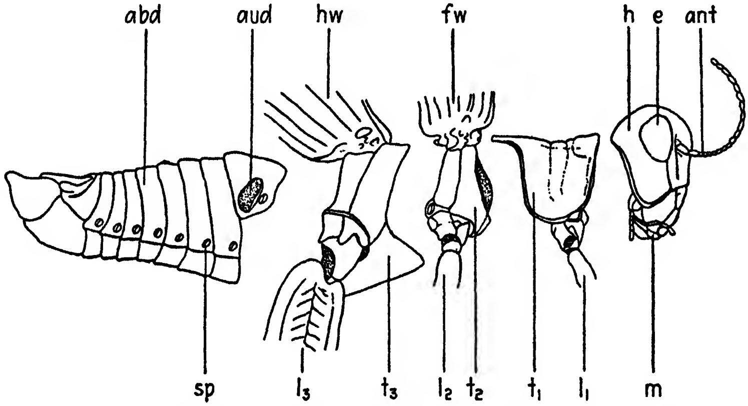


FIG. 110.—External anatomy of male grasshopper, × 3. *h*, head; *ant*, antenna; *e*, compound eye; t_1, t_2, t_3, thorax; l_1, l_2, l_3, legs; *fw*, fore wing; *hw*, hind wing; *abd*, abdomen; *aud*, auditory organ; *s*, spiracle. (*After Packard.*)

tion. In some localities they are very abundant during the late summer and autumn.

External Features.—The body of an insect consists of three distinct regions: a *head*, a *thorax*, and an *abdomen* (Fig. 110). It is encased in a hard chitinous covering (*exoskeleton*), which is shed periodically to permit growth to occur. The head of the grasshopper is composed of five or six metameres, which have become fused to such an extent that their individuality is lost. The other metameres are distinct and easily recognized, three of them making up the thorax and ten the abdomen.

The head bears a pair of large *compound eyes* and three simple eyes, or *ocelli*, the latter being arranged in the form of a triangle

[1] Some of the millipedes have a pair of *aggregate eyes*, each consisting of a small group of simple eyes that are not so closely organized as the facets of a compound eye.

on the front of the head. As in the crayfish, each compound eye is composed of several thousand hexagonal units called *facets*, each of which forms its own image, although perhaps only a partial one. The head of the grasshopper bears four pairs of jointed appendages. In the order of their occurrence, they are the *antennae* (feelers), *mandibles* (biting jaws), *first maxillae*, and *second maxillae*. The second maxillae are united laterally to form the *labium* (lower lip). The mandibles and two pairs of maxillae, together with the flap-like *labrum* (upper lip) and the small *hypopharynx* (tongue), constitute the mouth parts of the grasshopper (Fig. 111). They are typical biting mouth parts such as characterize generalized insects. The mouth parts of insects that obtain their food by sucking are considerably modified, although constructed according to the same general plan as those of the grasshopper.

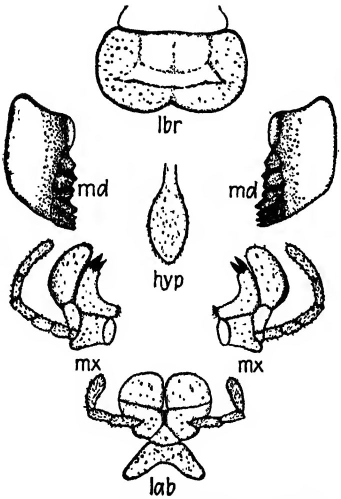


FIG. 111.—Mouth parts of grasshopper, × 4. *lbr*, labrum; *md*, mandible; *hyp*, hypopharynx; *mx*, first maxillae; *lab*, second maxillae forming labium.

The thorax bears three pairs of jointed *legs*, one pair on each metamere. Three pairs of legs are characteristic of practically all insects. In the grasshopper the hind legs are very large and are adapted for jumping. Almost all insects have two pairs of *wings*, which are attached to the second and third thoracic metameres. Wings are not appendages but merely outgrowths of the body wall. Insects differ considerably in the character of their wings; in the grasshopper the fore wings are thin, narrow, and but slightly hardened, while the hind wings are large, membranaceous, and folded beneath the fore wings like a fan when the insect is not flying.

In the more primitive arthropods all or nearly all the abdominal metameres bear appendages, but in all except the very lowest insects no abdominal appendages are present. In the grasshopper the first abdominal metamere, which is incomplete,

bears a pair of *auditory organs.* The last abdominal metamere in the female is modified to form an egg-laying organ, the *ovipositor,* while in the male it has two structures for transferring sperms. *Spiracles,* or breathing pores, occur in pairs on all the metameres back of the head except the third thoracic segment and the last two abdominal ones.

Digestive System.—The digestive system of the grasshopper consists of a *mouth,* a short curved *esophagus,* a large sac-like *crop,* a small muscular *gizzard,* a large thin-walled *stomach,* and

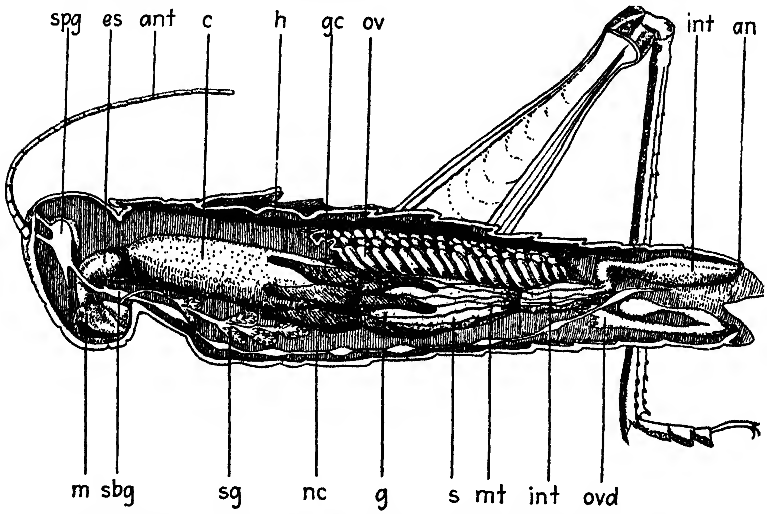


FIG. 112.—Dissection of female grasshopper (*Melanoplus*). *ant,* antenna; *m,* mouth; *es,* esophagus; *c,* crop; *g,* gizzard; *s,* stomach; *int,* intestine; *an,* anus; *sg,* salivary glands; *gc,* gastric caeca; *h,* heart; *mt,* Malpighian tubes; *spg,* supra-esophageal ganglion; *sbg,* subesophageal ganglion; *nc,* nerve cord; *ov,* ovary; *ovd,* oviduct. (*Modified after Jewell model.*)

a long slightly coiled *intestine,* which ends at the *anus* (Fig. 112). Certain digestive glands are also present, *viz.,* several pairs of tubular *salivary glands* emptying into the mouth, and six or eight large *gastric caeca* opening into the anterior end of the stomach. These secrete digestive fluids into the alimentary canal.

Circulatory System.—Situated directly below the dorsal abdominal wall is a long, thick-walled, contractile *heart.* It is partially divided into eight chambers and furnished with valves that permit all the blood to flow forward. From it a slender branched vessel extends into the head. As in the mollusks and

in the other arthropods, the blood flows out into sinuses, which are divisions of the coelom. It finally returns to the heart, entering through lateral openings. As in the crayfish, the blood of insects is colorless, consisting of a plasma and numerous amoeboid corpuscles, but a peculiar feature is that it carries no oxygen or carbon dioxide, only food and nitrogenous wastes. For this reason the circulatory system of the grasshopper is not so well developed as that of the crayfish.

Respiratory System.—This is entirely distinct from the circulatory system and consists of a large number of fine connected tubes called *tracheae,* which form an internal network carrying oxygen directly to the tissues in all parts of the body (Fig. 145). The tracheary system is connected with large air sacs, which give buoyancy to the insect in flight; it communicates with the outside air through the spiracles. The entrance and exit of air are caused by rhythmic contractions of the body wall.

Excretory System.—The excretory organs of the grasshopper consist of a large number of *Malpighian tubes.* These are delicate, highly coiled structures extending throughout the coelom and opening into the anterior end of the intestine. They remove nitrogenous wastes from the blood by absorption through their thin walls. It is an interesting fact that a very primitive arthropod (*Peripatus*), belonging to a class of its own, has retained paired metameric nephridia such as characterize the segmented worms.

Nervous System.—The general features of the nervous system are similar to those of the earthworm and crayfish. Two large ganglia are present in the head, the larger one above and the smaller one below the esophagus. These are called the *supraesophageal ganglion* and the *subesophageal ganglion,* respectively. They are connected with each other by means of a pair of nerve cords encircling the esophagus. Nerves extend from these ganglia to the eyes, antennae, and mouth parts. Of the other ganglia, three occur in the thorax and five in the abdomen, all connected by a double ventral nerve cord, the two parts of which are separate in the thorax and united in the abdomen. It sends out nerves to various parts of the body. Many of the ganglia have been formed by the fusion of smaller ones.

Reproductive System.—In all insects male and female organs are borne on separate individuals. A pair of *testes,* consisting

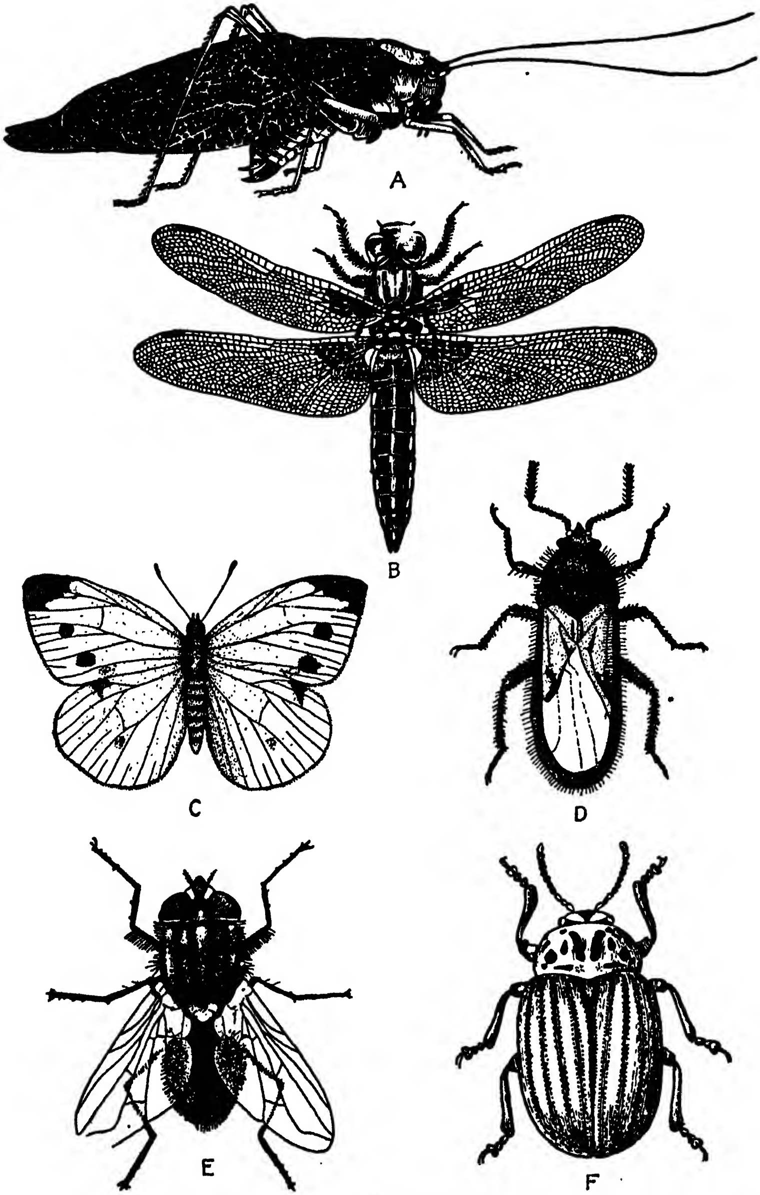


Fig. 113.—Representative insects. *A*, katydid (*Microcentrum*); *B*, dragonfly (*Libellula*); *C*, cabbage butterfly (*Pieris*); *D*, chinch bug (*Blissus*); *E*, house fly (*Musca*); *F*, potato beetle (*Leptinotarsa*). (*Redrawn from Newman, "Outlines of General Zoology," The Macmillan Company, after various authors, by permission.*)

of a mass of tubules, is located above the intestine, each being connected with the last metamere by means of a slender *sperm duct.* The two *ovaries* are also tubular and situated in the abdomen. The eggs reach the ovipositor through a pair of *oviducts.* After fertilization, which occurs within the female's body, the eggs are laid in the ground in masses of 20 to 35 and later hatch into young called *nymphs.* These are essentially like the adults except for their small size, wingless condition, and bodily proportions. The higher insects undergo a *metamorphosis*, the young being worm-like larvae (see pp. 241–242).

Other Insects.—The insects, numbering over 600,000 species, constitute the largest group of arthropods, and include an enormous variety of forms. The most primitive insects are the springtails and fish moths—small wingless creatures without compound eyes and in some cases with abdominal appendages. The grasshoppers, crickets, and cockroaches have biting mouth parts. Their anterior wings are straight and leathery, covering the posterior membranaceous wings when folded (Fig. 113*A*). The dragonflies also have biting mouth parts, but both pairs of wings are membranaceous and about equal in size (Fig. 113*B*). The butterflies and moths have sucking mouth parts and scaly wings (Fig. 113*C*). Most of the true bugs have membranaceous wings, but in some the fore wings are thickened at the base. Sucking mouth parts are present (Fig. 113*D*). The flies and mosquitoes also have sucking mouth parts but have only one pair of wings (Fig. 113*E*). The beetles have biting mouth parts and hard fore wings that meet in a straight line and serve as covers for the membranaceous hind wings (Fig. 113*F*). In the ants, bees, and wasps all the wings are membranaceous, the hind pair being smaller than the fore pair. The mouth parts are adapted for biting and sucking (Fig. 140).

In all insects the body has three separate divisions: head, thorax, and abdomen. One pair of antennae is present, and in most cases there are two compound and three simple eyes. Nearly all insects have six legs and two pairs of wings. Except in a few primitive forms, abdominal appendages are absent. The circulatory and respiratory systems are entirely distinct from each other, the latter consisting of tracheae. The excretory system is composed of Malpighian tubes.

The Arachnids.—The arachnids constitute a distinct class of arthropods numbering about 20,000 species. Here belong the spiders, daddy longlegs, king crabs, scorpions, mites, and ticks (Fig. 114). Metamerism is apparent in the scorpions and daddy longlegs, but is externally indistinct in the other arachnids. The scorpions have claw-like maxillae that are often large and power-

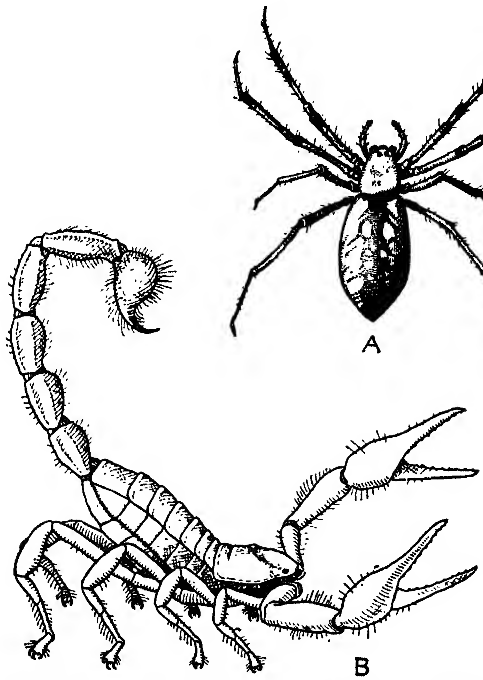


FIG. 114.—Arachnids, natural size. *A*, a scorpion (*Hadrurus hirsutus*); *B* garden spider (*Argiope aurantia*).

ful. Their abdomen is differentiated into two portions and bears a terminal sting.

In nearly all arachnids the body consists of a cephalothorax and an abdomen. Antennae and compound eyes are lacking, but a variable number of simple eyes are present. Wings are never developed. Arachnids have four pairs of legs, and, except in the king crabs, are entirely without abdominal appendages. Respiration takes place in characteristic organs called *lung books*, rarely in tracheae. The excretory organs consist of Malpighian tubes.

General Features of Arthropods.—The arthropods are similar to the segmented worms in being bilaterally symmetrical, triploblastic, metameric animals with highly developed systems and an enteron with two external openings. They differ in having a reduced coelom, a chitinous outer covering, distinct body regions, and jointed appendages. In the crustaceans the body covering is impregnated with lime. Insects have a distinct head, thorax, and abdomen, while in the arachnids and most crustaceans the head and thorax are fused. The myriapods have retained a worm-like body with a head, but with no distinction between thorax and abdomen. In the two primitive classes (crustaceans and myriapods) nearly every segment, as a rule, bears a pair[1] of jointed appendages, but in the more advanced groups (insects and arachnids) appendages have disappeared from the abdomen.

[1] Two pairs in the millipedes.

CHAPTER X

THE VERTEBRATES

The presence or absence of a backbone forms the basis of distinction between vertebrates and invertebrates, and it was once thought that all animals belong to either one or the other of these two divisions. A few forms are known, however, which are intermediate, possessing no true backbone, but having certain fundamental features in common with the backboned animals. Thus the highest group in the animal kingdom—the *Chordata*—includes not only the *Vertebrata*, but also a few primitive members that may be referred to as *Provertebrata.*

CHORDATA

The chordates, numbering about 40,000 species, are a smaller group than either the arthropods or the mollusks but show a great advance over them in many ways. Like all the higher invertebrates, the chordates are bilaterally symmetrical, triploblastic animals with a coelom and an enteron, the latter having two openings. They resemble the annelids and arthropods in being fundamentally metameric; but, except in the lower chordates, there are no external evidences of metamerism in the adult stage of development. Internally, however, and in the embryo externally as well, a segmental arrangement of certain parts is apparent. With rare exceptions, jointed appendages are present. The chordates are characterized by three distinctive features, as follows:

1. All chordates have, at least in early life, an unbroken rod of supporting tissue called the *notochord.* In the provertebrates this structure may persist throughout life or may later disappear, but no additional skeletal structures are formed. In the vertebrates, on the other hand, a *vertebral column* (or "backbone") arises which is made up of a linear series of units called *vertebrae.* As a rule, the vertebral column replaces the notochord, which is then purely an embryonic structure, but in the lower fishes it

persists throughout life supplemented by the vertebrae. No animals other than chordates have a notochord.

2. All chordates have paired *gill slits* at an early stage in their development. These are clefts in the lateral walls of the pharynx. In the gill-breathing forms these structures persist throughout life, permitting an outward passage of water from the mouth cavity over the gills. In the lung-breathing chordates the gill slits disappear early in life, being solely embryonic or larval structures.

3. In chordates the nerve cord is hollow, being in reality not a "cord" but a tube, and is invariably dorsal to the alimentary canal, never ventral to it as in the annelids and arthropods. In

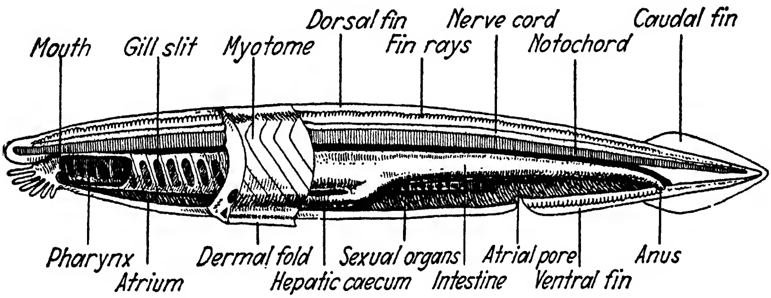


FIG. 115.—The lancelet (*Amphioxus lanceolatus*), a primitive chordate, × 2.

the vertebrates, the nerve cord is enclosed by the vertebral column.

The Provertebrates.—The three types of animals described below are very dissimilar in their general appearance and at first glance would seem to have nothing in common. They all agree, however, in possessing basic chordate characters. The first form is especially interesting in that it represents, in its organization, a possible ancestral stage through which the vertebrates may have passed in their early evolution.

The Lancelet.—The lancelet (*Amphioxus*) is a marine, fish-like animal about 2 inches long (Fig. 115). It may swim rapidly through the water but usually lies buried in sand or mud near the shore. The elongated body tapers at both ends and is laterally compressed. It has a long median *fin* running along the dorsal side, around the tail, and ending back of the anus. From that point a pair of lateral *dermal folds* extends forward.

The muscles in the body wall are V-shaped and have a segmental arrangement. They are known as *myotomes*.

The lancelet does not have a definite head. The *mouth* is located on the ventral surface a short distance from the anterior end of the body. No jaws are present. The mouth opens into a sac-like *pharynx*, which is pierced by many pairs of *gill slits*. Water enters the mouth and passes through the gill slits, giving

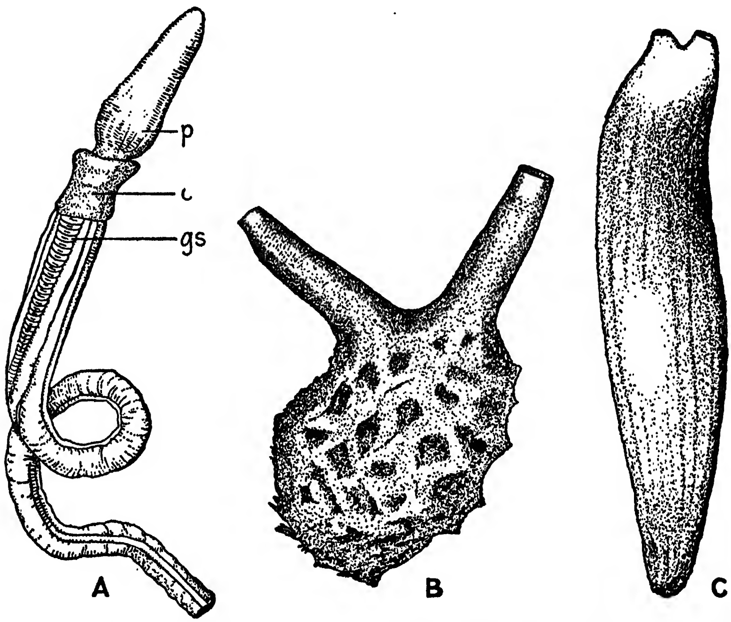


FIG. 116.—Primitive chordates. *A*, the acorn-tongue worm (*Balanoglossus*), slightly enlarged; *B*, a sea squirt or tunicate (*Cynthia*), natural size; *C*, another sea squirt (*Styela*), natural size; *p*, proboscis; *c*, collar; *gs*, gill slits. (*A*, *after A. Agassiz; B and C, after Ritter.*)

up oxygen to the blood in the gills. It then enters the *atrium*, a chamber that partially encloses the pharynx, and leaves through the *atrial pore*. Food particles taken in through the mouth pass directly from the pharynx to the straight *intestine*, which terminates at the *anus*. The *notochord*, extending the entire length of the body, lies just beneath the *nerve cord* and above the alimentary canal. There is no skull and no brain. An important feature is the occurrence of paired nephridia, which open into the coelom, suggesting a remote affinity with the annelids.

The Acorn-tongue Worm.—Another primitive chordate, the acorn-tongue worm (*Balanoglossus*), is also found along seacoasts where it lies buried in the mud. It is a worm-like animal having a *proboscis*, *collar*, and *trunk* (Fig. 116*A*). The *mouth* is located between the proboscis and the collar. It opens into a *pharynx* from which a number of paired *gill slits* communicate with the outside. The *notochord* is small and located within the proboscis. Four longitudinal *nerve cords* are present in the trunk, the dorsal one being tubular and slightly larger than the others. The larva of *Balanoglossus* is ciliated and motile and closely resembles the larvae of the echinoderms.

The Sea Squirts.—The sea squirts, or *tunicates*, are degenerate chordates that may be either free swimming or permanently

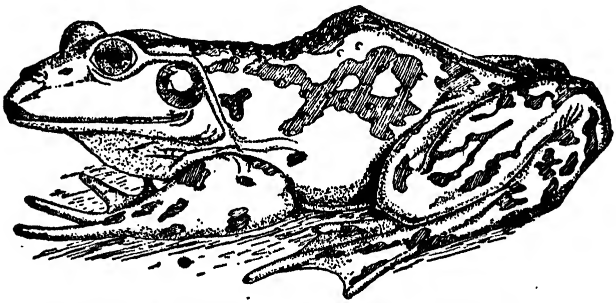


FIG. 117.—The bull frog (*Rana catesbiana*), one-half natural size. The head, trunk, limbs, mouth, nostrils, eyes, and eardrums are easily recognizable.

attached to rocks and piles along seacoasts. Some are solitary, others colonial. The body is mostly sac-like and enclosed in a tough coat or *tunic* (Fig. 116*B* and *C*). Water enters through a long upper tube and is expelled through a lower one. There is a *pharynx*, with *gill slits*, and a nervous system consisting of a single ganglion, but no notochord is present. It is chiefly in the larval stage that a relationship to other chordates is revealed. The larvae are free-swimming creatures resembling small tadpoles. A short functional *notochord* is present in the tail, dorsal to which is a tubular *nerve cord*.

The Frog.—Most of the features of a typical vertebrate may be seen in the frog. Frogs are common inhabitants of marshes and other wet places, a number of species occurring in the United States. The largest of these is the bull frog (*Rana catesbiana*, Fig. 117), but the leopard frog (*R. pipiens*), easily recognized by

its color pattern, is the commonest species in the eastern and central parts of the country. The frog belongs to the second of the five great classes of vertebrates. These are the fishes, amphibians, reptiles, birds, and mammals.

External Features.—The body of a typical vertebrate is divided into *head*, *trunk*, and *tail*, but the frog has a tail only in early life (Fig. 117). The head bears a pair of large *eyes*, a pair of *nostrils*, and a pair of *eardrums*. The vertebrate eye has a characteristic structure very different from that of mollusks or arthropods. The eye of the frog is provided with two eyelids, but only the lower one is movable. The nostrils open into the large mouth cavity. Two *jaws* are present: an upper one firmly fastened to the cranium, and a lower movable one. The body is covered with a smooth, moist, scaleless skin containing numerous mucus-secreting glands. Two pairs of *limbs* are present, which in typical vertebrates are *pentadactyl*—having five *digits* (fingers and toes). The hind limbs of the frog have five digits, but the fore limbs have only four, the thumb being present in a very rudimentary condition. The hind feet are webbed, obviously an adaptation for swimming. The short fore legs merely support the body, but the hind legs are long and powerful, being used both in jumping and in swimming. None of the digits bears claws.

Digestive System.—The *mouth* of the frog is very large. *Teeth* are borne in a single row on the upper jaw and also in two localized groups on the roof of the mouth, but none occurs on the lower jaw. The teeth are small and all alike. They are used not for chewing but merely for holding the food, this being swallowed whole. The fleshy *tongue*, notched posteriorly, is attached at its forward end and is suddenly thrust out in capturing worms, snails, and small insects. The capture and swallowing of food are facilitated by the presence of slime on the tongue and in the mouth cavity. The extensive mouth cavity leads into a short *esophagus*, which joins the thick-walled, sac-like *stomach* (Fig. 118). Then follows the long coiled *small intestine* and finally the short *large intestine*. The latter opens into a cavity termed the *cloaca*, where waste products of digestion accumulate, finally leaving the body through the *anus*. The cloaca also receives products from the kidneys and the reproductive organs. All vertebrates have a cloaca except some of the fishes and almost all of the mammals.

The digestive system of the frog includes not only the digestive organs just mentioned, but also several *digestive glands.* The largest of these is the red three-lobed *liver.* Attached to the liver is the small green *gall bladder*, which stores *bile*, a substance produced by the liver. The bile is carried from the gall bladder to the anterior end of the small intestine by a slender tube called the *bile duct.* Another digestive gland present in the frog is the

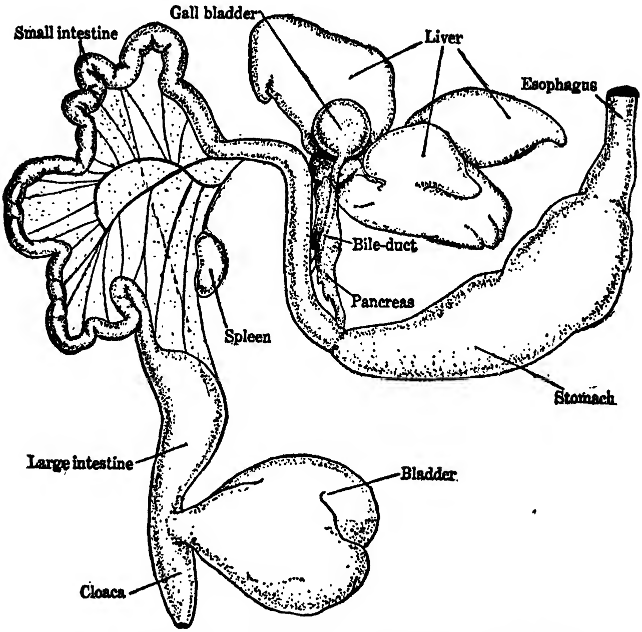


Fig. 118.—Digestive system of the frog. The stomach has been moved to the right, the three lobes of the liver turned back, and the small intestine spread out to the left.

pancreas, a white irregular body lying next to the stomach. It secretes a digestive fluid into the small intestine through the bile duct. A third gland should be mentioned, the *spleen*—a small, red, globular body located near the point where the small and large intestine join. It is not connected with the digestive system and has nothing to do with the work of digestion.

Respiratory System.—The frog has a pair of sac-like *lungs* lying in the anterior part of the coelom close to the dorsal body wall (Fig. 119). Their inner surface is increased by simple folds, which form minute air sacs that open into a large undivided

central cavity. The animal breathes with its mouth closed. Air is inhaled through the nostrils into the mouth cavity. The nostrils are then closed, and, by a contraction of the throat muscles, the air is forced through a slit in the floor of the mouth, called the *glottis*, to a pair of *bronchial tubes*, one of which goes to each lung. In the higher vertebrates a *trachea* (windpipe) extends from the glottis to the bronchial tubes. In the lungs there is an elaborate network of *capillaries* (small blood vessels) through the walls of which oxygen is taken up and carbon dioxide given off. Instead of being immediately expelled, the air taken into the lungs of the frog remains for a considerable time, being kept there by closure of the glottis. Meanwhile rhythmic contractions of the throat force air through the nostrils into and out of the large mouth cavity, where the moist mucous membrane provides additional respiratory surface. A considerable amount of respiratory gas exchange also takes place through the moist skin, which is abundantly supplied with mucous glands and blood vessels. This feature makes it possible for the frog to remain under water for a considerable length of time without having to come to the surface.

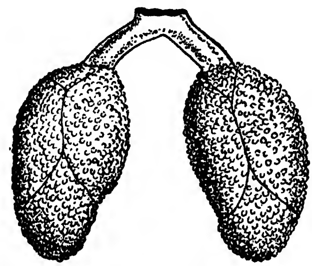


FIG. 119.—Respiratory organs of the frog, comprising the lungs and bronchial tubes.

In man and other mammals the coelom is divided by a transverse muscular partition, called the *diaphragm*, into a thoracic and an abdominal cavity. The lungs lie in the thoracic cavity. Air is forced into and out of them chiefly by movements of the chest and diaphragm.

Circulatory System.—The circulatory system of a vertebrate consists of a *heart*, which pumps the blood, and of *arteries*, *veins*, and *capillaries*, through which it circulates. The heart is enclosed in a sac called the *pericardium*. Blood is carried away from the heart by the arteries, the larger ones giving rise to smaller and smaller branches that finally end in capillaries. These have very thin walls through which diffusion takes place. Capillaries transfer nourishment and oxygen to the living tissues and remove waste products from them. They are connected with the veins, which transport the blood back to the heart. Thus vertebrates

have a *closed circulatory system,* in contrast to the *open system* seen in the higher invertebrates, where the blood flows out of the ends of vessels into sinuses. Vertebrates that breathe with lungs have a more complicated circulatory system than the more primitive gill-breathing forms have. For this reason we shall first consider the circulation of blood in a fish.

Circulation in Fishes.—The heart of a fish consists of two fundamental chambers: an *auricle* and a *ventricle* (Fig. 120). These are separated by valves so that the blood may flow only in one direction. Impure blood from all regions of the body is carried to the heart by the veins and is poured into the auricle.

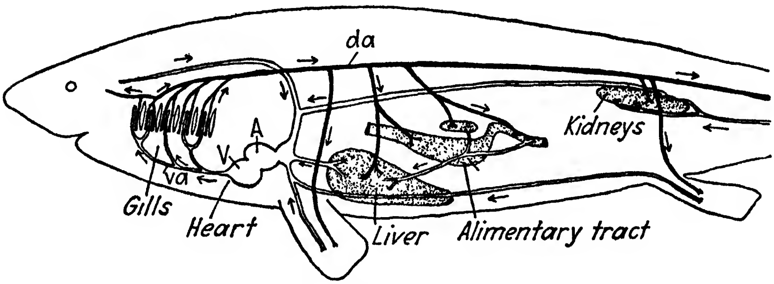


FIG. 120.—Diagram of the circulatory system of the dogfish, side view. *A*, auricle; *V*, ventricle; *da*, dorsal aorta; *va*, ventral aorta. Only the larger blood vessels are shown. The arrows indicate the direction of blood flow. (*After Wieman.*)

After passing into the ventricle, which has thick muscular walls, it is forced forward through the *ventral aorta,* which gives off branches to the gills. There it passes into capillaries where it absorbs oxygen from the water and liberates carbon dioxide. From the gills the purified blood passes into arteries leading to the *dorsal aorta,* which extends backward the entire length of the body, giving off branches to all the principal organs. After passing into capillaries, where it gives up its oxygen and food and collects waste products, it then returns to the heart through the veins. The most important feature to be kept in mind regarding circulation in the fishes is that the heart contains only impure blood, and consequently the blood makes a single circuit in going from the heart to the various organs and back again.

Circulation in Amphibians.—The frog's heart is three-chambered, there being a *left auricle,* a *right auricle,* and a *ventricle* (Fig. 121). The ventricle has much thicker walls than the

auricles. As in the fishes, the veins carry blood to the heart, but here these comprise two sets: (1) *systemic veins*, which bring impure (non-aerated) blood to the heart from all parts of the body except the lungs, and (2) *pulmonary veins*, which carry pure (aerated) blood from the lungs. Impure blood from the head, fore limbs, and body wall goes directly to the heart, but that coming from other regions goes first either to the liver or to the kidneys.

The systemic veins empty their blood into the right auricle. Pure blood coming from the lungs through the pulmonary veins enters the left auricle. Both auricles force blood into the ventricle at the same time, which then contracts before much mixing of pure and impure blood is possible. Because the arterial system arises from the right side of the ventricle, the first blood to leave the heart is largely impure. It goes to the lungs and skin to be aerated. The next blood, which is mixed, goes to other parts of the trunk, while the last blood is largely pure and goes directly to the head. This distribution of blood, as well as its constant flow in the same direction through the heart, is brought about by the presence of valves.

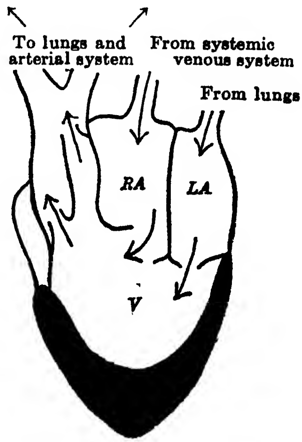


Fig. 121.—Diagram of heart of frog, ventral view. *RA*, right auricle; *LA*, left auricle; *V*, ventricle. The arrows indicate the direction of the blood flow.

It is evident that, in contrast to the fishes, amphibians have a *double circulation*. This means that the blood makes two complete circuits in the body. After leaving the various organs, it goes to the heart, then to the lungs, then back to the heart, and finally to the various organs again.

Circulation in Mammals.—In the highest group of vertebrates, the mammals, the heart is four chambered, consisting of two auricles and two ventricles (Fig. 122). The auricles are thin walled and the ventricles thick walled. The impure blood, poured into the right auricle from the systemic venous system, goes into the right ventricle and then, through the pulmonary artery, to the lungs to be aerated. Returning to the heart

through the pulmonary veins, the pure blood enters the left auricle, passes into the left ventricle, and thence out through the aorta into the arterial system and to all parts of the body. Valves prevent the blood from flowing backward from the ventricles into the auricles and from the arteries into the ventricles. Because in the mammals the pulmonary and systemic circulations are entirely distinct, and because the left and right halves of the heart are completely separated from each other, no mixing of pure and impure blood is possible. Thus it is evident that the mammals have a more perfect scheme of circulation than the amphibians, and one representing a higher state of evolution.

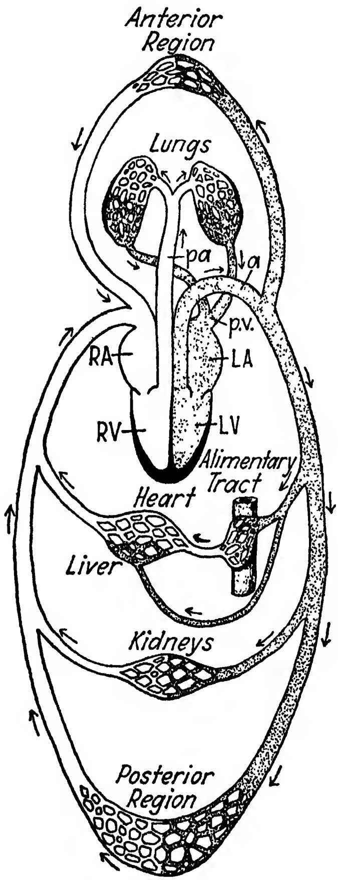


Fig. 122.—Diagram showing the general scheme of circulation in a mammal, ventral view. *RA*, **right auricle;** *LA*, **left auricle;** *RV*, **right ventricle;** *LV*, **left ventricle;** *a*, **aorta,** *pa*, **pulmonary artery;** *pv*, **pulmonary veins. The arrows indicate the direction of blood flow.**

Excretory System.—A pair of oval dark-red *kidneys* lie in the coelom close to the dorsal body wall (Fig. 126). Kidneys are present in all vertebrates. Each consists of a mass of tubules somewhat resembling the nephridia of the earthworm. In the frog, some of the veins, in going to the heart, pass through the kidneys and give up nitrogenous waste products to them. The kidneys are connected with the cloaca by means of a pair of tubes called *ureters*. The *bladder* is a sac that stores the liquid waste products excreted by the kidneys until expelled through the anus. In the frog the bladder is a lateral outgrowth of the cloaca, but in the fishes and the higher vertebrates it is a very different organ, being a dilation of the ureters.

Skeletal System.—The body of the frog is supported by an internal framework (*endoskeleton*) of bones and cartilages (Fig. 123), as in all vertebrates except the more primitive fishes, where

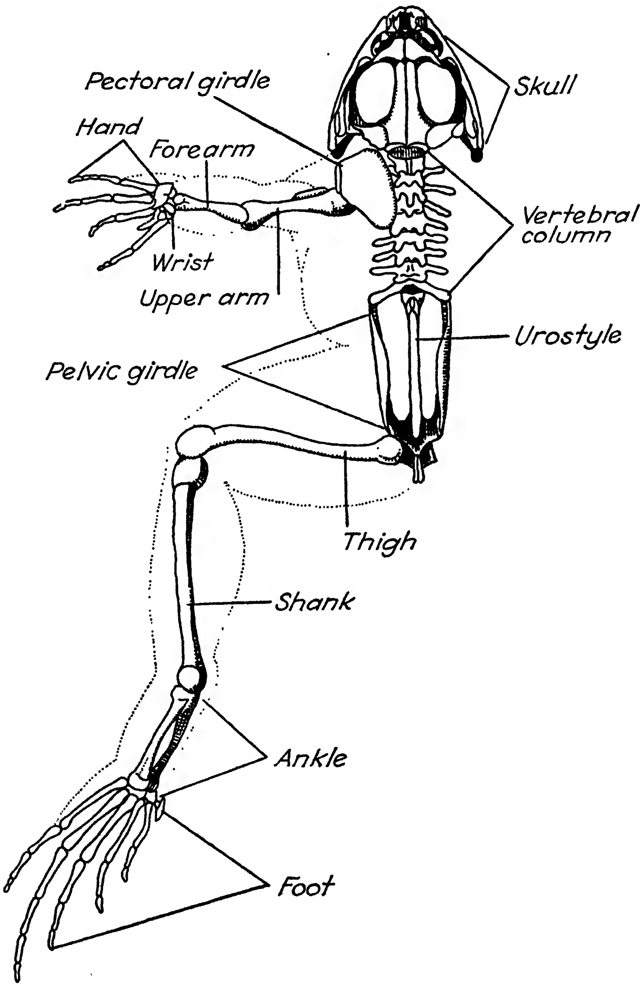


Fig. 123.—Skeleton of frog, dorsal view, with right limbs removed, natural size. (*Redrawn from Linville, Kelly, and Van Cleave, "General Zoology," Ginn and Company, after Duges, by permission.*)

the skeleton is entirely cartilaginous. The skeleton not only supports the body but provides places of attachment for muscles and protects such delicate organs as the eyes, brain, and spinal

cord. The skeletal system of the frog consists of an *axial skeleton* and an *appendicular skeleton.* The former includes the *skull* and *vertebral column,* the latter the two pairs of *limbs* and their supporting *limb girdles.*

The skull includes the *cranium,* or brain case, the *jaws,* and certain other associated supporting structures. The vertebral column, serving as a supporting axis for the body, is composed of

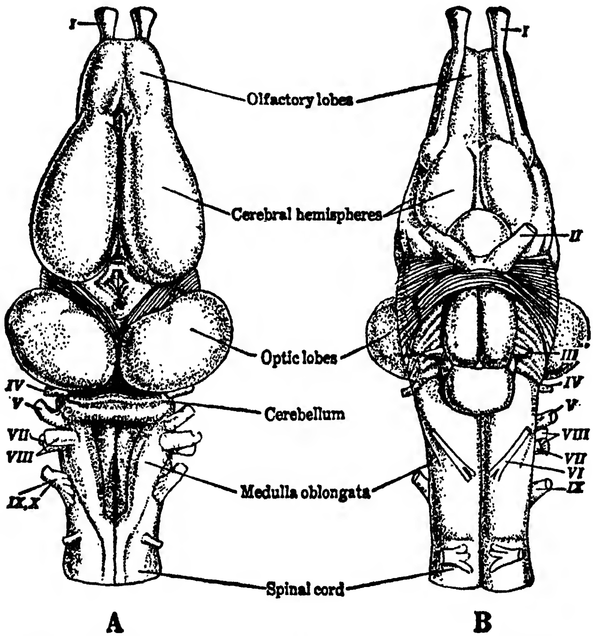


Fig. 124.—Brain of frog. *A,* **dorsal aspect;** *B,* **ventral aspect;** *I* **to** *X,* **cranial nerves.** *(After Jewell model.)*

nine separate *vertebrae* and a long posterior bone called the *urostyle.* The urostyle is generally interpreted as a vestigial tail. Each vertebra except the first bears a pair of short transverse processes, the last pair being attached to the hip girdle. True ribs, such as occur in nearly all other vertebrates, are lacking in the frog. A *sternum,* or breastbone, is fastened to the shoulder girdle, which, unlike the hip girdle, is not joined to the vertebral column. Each fore limb consists of an *upper arm, forearm, wrist,* and *hand* with four *digits.* Each hind limb is made up of a *thigh, shank, ankle,* and a *foot* with five *digits.* The fore limbs are

attached to the *pectoral* (shoulder) *girdle*, the hind limbs to the *pelvic* (hip) *girdle*.

Nervous System.—As contrasted with the invertebrates and lower chordates, all vertebrates have a complex *brain* enclosed

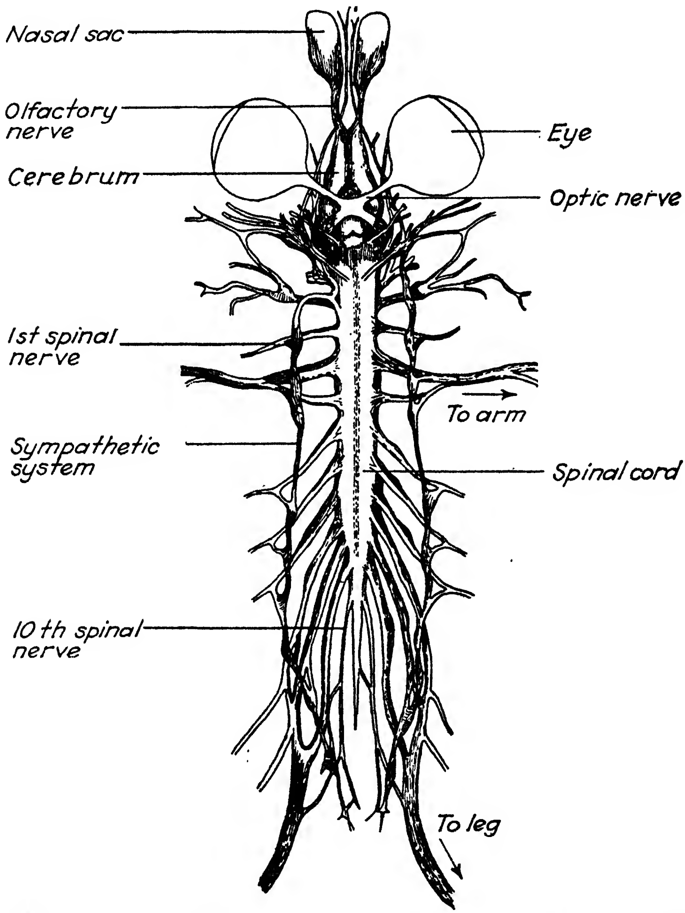


FIG. 125.—Central nervous system of the frog, showing cranial and spinal nerves and sympathetic nervous system, ventral view. (*After Ecker.*)

by the cranium. The brain has certain highly specialized parts, the chief ones being a pair of *olfactory lobes*, a pair of *cerebral hemispheres*, a pair of *optic lobes*, a *cerebellum*, and a *medulla oblongata* (Fig. 124). Although these parts are present in all

vertebrates, each group exhibits differences in its degree of development. Thus in the frog the cerebral hemispheres and cerebellum are relatively small, while in the mammals these parts are very large (Fig. 124).

Vertebrates have also a *spinal cord*, a thick tube of nerve tissue extending backward from the brain and enclosed by the vertebral column (Fig. 125). The location of the nerve cord above the enteron is in striking contrast to its position in the segmented worms and arthropods. The brain of the frog gives rise to 10 pairs of *cranial nerves*, which go to the sense organs and other important parts of the body, while the spinal cord gives rise to 10 pairs of *spinal nerves.* The latter innervate the skin and the muscles of the trunk and limbs. All the principal nerves have many branches.

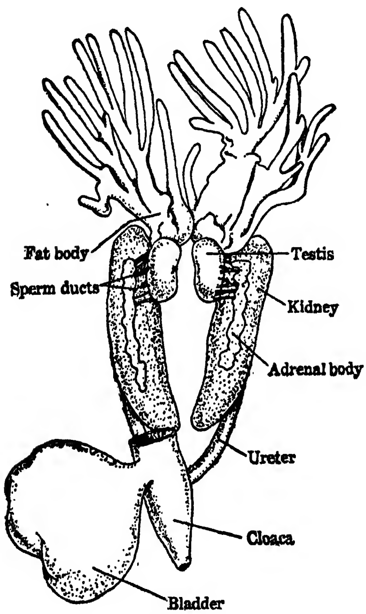


FIG. 126.—Excretory and male reproductive systems of the frog.

The *central nervous system* comprises the brain and spinal cord, while the nerves that emerge from them, with all their branches, constitute the *peripheral nervous system.* In addition, vertebrates have also a *sympathetic nervous system,* consisting of a chain of ganglia on each side of the spinal cord and connected with branches of the spinal nerves (Fig. 125). From these ganglia, nerves extend to the various internal organs, chiefly the organs of digestion and circulation, controlling their activities.

Reproductive System.—In the male frog a pair of small, yellow, oval *testes* lie beneath the kidneys and are connected with them by means of a number of slender *sperm ducts* (Fig. 126). Through these the sperms pass to enter the kidneys, leaving the body by way of the ureters and the cloaca. In the higher vertebrates the excretory and reproductive ducts are separate, and consequently the sperms do not pass through the kidneys and ureters.

The female frog has a pair of irregular sac-like *ovaries*, which lie below the kidneys but nearly fill the coelom when they are full of ripe eggs (Fig. 127). The pair of long coiled *oviducts*, through which the eggs leave the body, are not connected with the ovaries, but open into the coelom. The eggs are liberated by

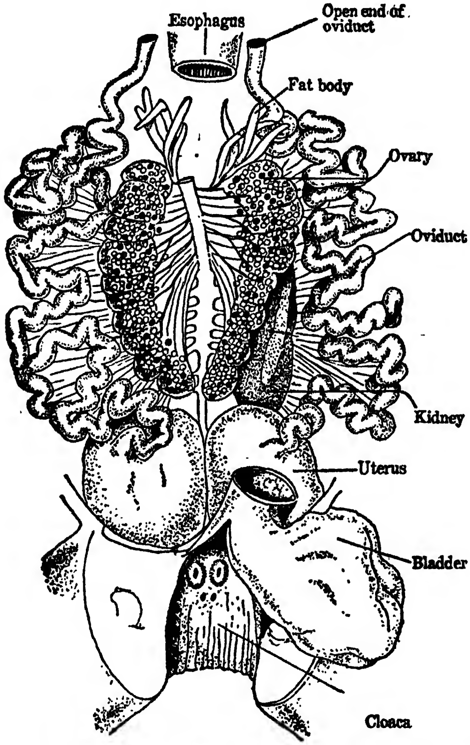


FIG. 127.—Female reproductive system of the frog. (*After Pfurtscheller wall chart.*)

a rupture of the ovarian wall. Passing into the coelom, they find their way to the open ends of the oviducts, which are funnel-like and ciliated.[1] As the eggs travel down the long coiled oviducts they receive a gelatinous coating. The lower end of each oviduct is dilated to form a distensible *uterus* where the eggs are temporarily stored. As the eggs leave the body through the

[1] In most of the higher vertebrates, the oviducts similarly have no direct connection with the ovary, but because the mouth of the oviduct lies very close to the ovary, the eggs do not remain in the coelom.

cloaca, they are fertilized by the male frog. Thus the embryos develop entirely outside the body.

In both sexes finger-like *fat bodies* are attached to the anterior end of the sexual organs (Figs. 126 and 127). Their exact function has not been accurately determined. They contain a large amount of fat and always decrease in size during the breeding

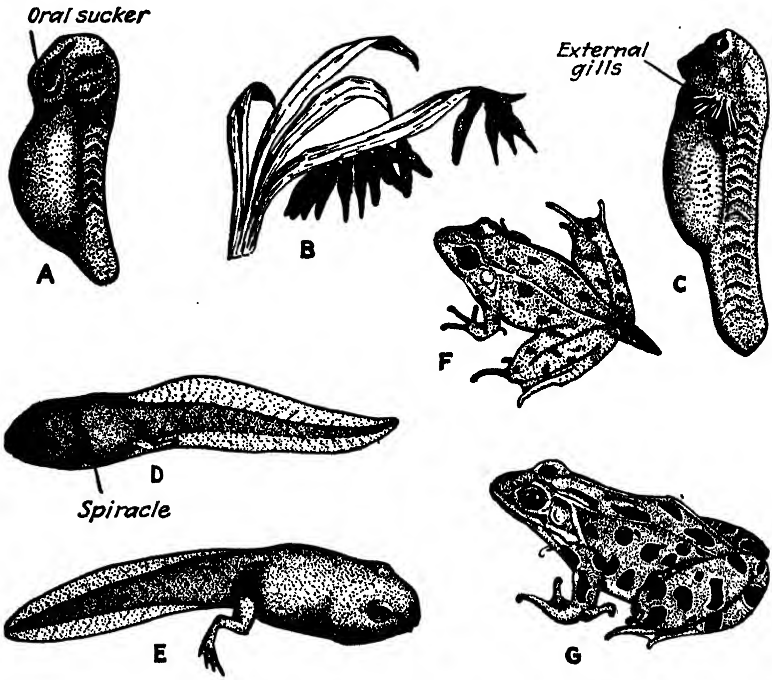


FIG. 128.—Stages in the development of the frog. (*From Wolcott, "Animal Biology."*)

season; for this reason it is thought that they contribute nourishment to the reproductive organs.

Development.—The eggs of the frog are always laid in water. They occur in gelatinous masses, each mass containing thousands of eggs. In about a week or 10 days after fertilization, the embryo becomes a *tadpole* (Fig. 128). When first hatched, the eyes, mouth, and gills have not yet fully developed, but these soon become visible. The first gills are external; later they disappear and are replaced by internal gills, which are enclosed by a fold of skin called the *operculum*. Water passes out of the

respiratory chamber through the *spiracle*, an opening on the left side. The tadpole not only has gills, but has a typical fish-like circulatory system with a two-chambered heart. A long tail is the organ of locomotion. Limbs are not developed until the tadpole has reached its full size. Gradually the hind limbs make their appearance, then the fore limbs, and, as both grow, the tail is slowly absorbed by the body. To complete the metamorphosis, the gills are replaced by lungs, the heart becomes three chambered, the intestine shortens, the mouth cavity enlarges, and other changes take place, all of which finally result in the transformation of the tadpole into a frog. The duration of the tadpole stage varies with different species, being about 3 months in the leopard frog and about 2 years in the bull frog.

THE GROUPS OF VERTEBRATES

As contrasted with the provertebrates, all vertebrates have a *cranium* (brain case) and a complex *brain*. The notochord, which invariably appears in the embryo, persists throughout life in the lower fishes but is supplemented by vertebrae. In all other vertebrates the notochord is largely or entirely replaced by a well developed *vertebral column*.

Fishes.—The fishes, numbering about 15,000 species, are highly specialized for aquatic life. Typically the body is elongated, laterally compressed, and tapered toward each end (Fig. 129). Fishes are cold-blooded[1] vertebrates having functional gills throughout life. In nearly all cases the skin is covered with scales. There are no limbs present, movement through the water being accomplished by means of fins and a long flexible tail. In the great majority of fishes both median *unpaired fins* and lateral *paired fins* are present. The latter, comprising the *pectoral* and *pelvic fins*, correspond to the fore and hind limbs, respectively, of the higher vertebrates. The heart is two chambered, but in the lungfishes is incompletely three chambered. Fertilization, in most cases, is external.

As in the lancelet, the muscles in the body wall occur in the form of zigzag segments (*myotomes*), which are metamerically arranged. A *lateral line*, the seat of special sense organs, is

[1] In "cold-blooded" animals the body temperature varies with the surroundings; in "warm-blooded" animals it is constant and relatively high, in man being normally 37° C. (98.6° F.).

present in fishes. Another characteristic feature, although not a universal one, is the occurrence of an *air bladder*, a large sac situated in the dorsal part of the coelom and concerned primarily with the maintenance of buoyancy. Modern fishes are of five chief types, as follows:

1. *Cyclostomes.*—The most primitive fishes constitute a small group comprising the lampreys and hagfishes (Fig. 130*A*). They differ so radically from the higher groups that they are generally regarded not as true fishes but as forming a class by themselves. The cyclostomes are parasites with a jawless,

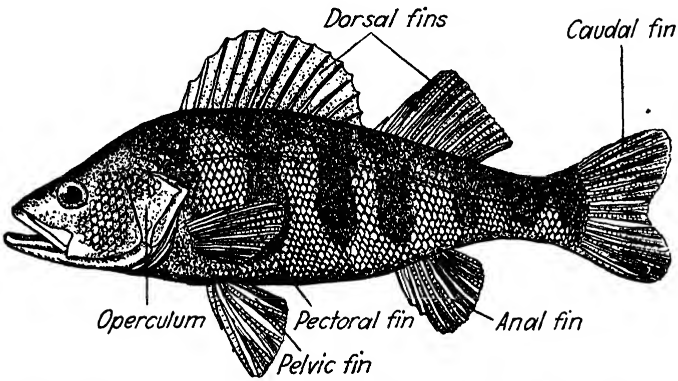


FIG. 129.—The yellow perch (*Perca flavescens*), a typical bony fish, one-half natural size. (*After Forbes.*)

funnel-shaped mouth by means of which they attach themselves to other fishes. In contrast to the higher groups, they lack not only jaws but also paired fins. The skin is smooth and without scales. No air bladder is present. A primitive feature is the presence of a persistent notochord, above which but not enclosing it lie the poorly developed vertebrae. The skeleton is entirely cartilaginous.

2. *Elasmobranchs.*—The sharks and rays constitute an old group exhibiting many primitive features (Fig. 130*B*). The vertebral column and other parts of the skeleton are much more highly developed than in the cyclostomes, but the notochord is persistent and the skeleton entirely cartilaginous. The gill slits are not covered by an operculum, as they are in all the higher fishes. The mouth is ventral and situated a short distance from the anterior end of the body. The tail is usually unequally lobed,

or *heterocercal*, the vertebral column extending into the upper lobe, which is larger than the lower one. The scales are of a primitive type, each consisting of a bony plate bearing a tooth-like spine. In contrast to the higher fishes, no air bladder is present.

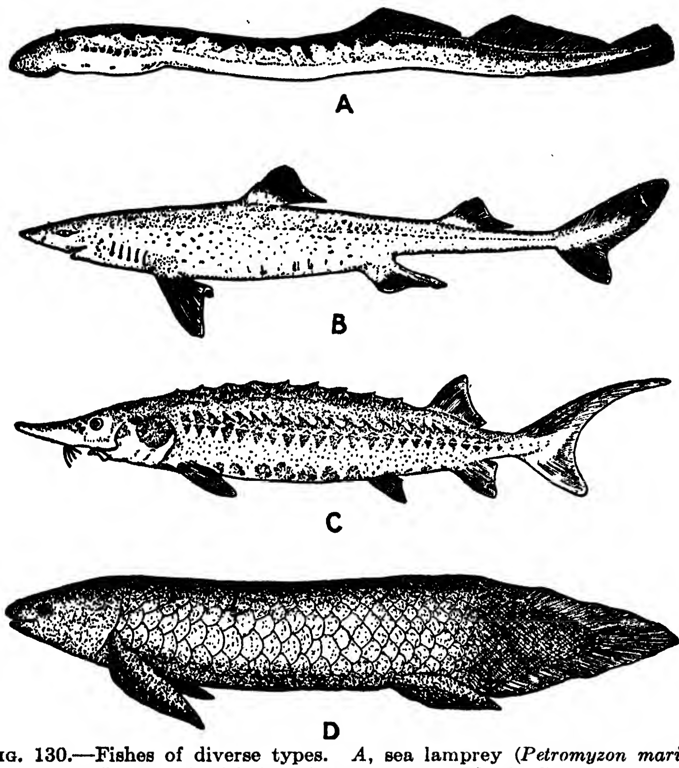


FIG. 130.—Fishes of diverse types. *A*, sea lamprey (*Petromyzon marinus*), a cyclostome; *B*, spiny dogfish (*Squalus acanthias*), a shark; *C*, common sturgeon (*Acipenser sturio*), a ganoid; *D*, Australian lungfish (*Neoceratodus miolepis*). *A*, *after Dean; B and C, after Jordan; D, after Günther.*)

3. *Ganoids*.—The ganoid fishes, also an old group, are represented chiefly by the sturgeons and gar pikes (Fig. 130*C*). The skeleton of the sturgeons is only partly ossified, but that of the gar pikes is more completely so. The sturgeons resemble the elasmobranchs in having a ventral mouth and a heterocercal tail, but in the gar pikes the mouth is terminal and the tail either heterocercal or homocercal (see next page). The scales are typically rhomboidal and enameled.

4. *Teleosts.*—These are the bony fishes, the great modern group including over 95 per cent of all existing species (Fig. 129). The skeleton is composed largely of bone. The mouth is terminal. The tail is usually outwardly symmetrical, or *homocercal,* the upper and lower lobes being equally prominent. The scales are round and overlapping.

5. *Lungfishes.*—The lungfishes are an ancient group, once abundant, but now represented by only three genera confined to Australia, South Africa, and Brazil (Fig. 130*D*). They live in stagnant pools and marshes. As in the elasmobranchs the notochord is persistent, but the skeleton is partly ossified. The scales are round and overlapping. All the lungfishes have gills, but the air bladder opens into the pharynx and functions as a true lung. An advanced feature of the group is the presence of a partial partition in the auricle, the heart thus being incompletely three chambered.

Amphibians.—This class includes only about 2,000 species. Amphibians are cold-blooded vertebrates with functional gills in early life. Some retain their gills and remain aquatic throughout their entire existence, but in most cases the gills are later replaced by lungs, and the animal adopts a terrestrial mode of life. A unique feature of the group is that, with rare exceptions, the skin is entirely without scales. Nearly all amphibians have four limbs which are typically pentadactyl, the toes being without claws. The heart is three chambered, there being two auricles and one ventricle. Fertilization, in most cases, is external and the eggs are laid in the water. As in all the higher groups, the muscles are arranged in longitudinal bands rather than in zigzag segments. Historically, the amphibians are an old group. They are thought to have arisen from some ancient fish stock, but not directly from the lungfishes. They were more abundant and diversified in the past than they are now. There are two chief groups of modern amphibians:

1. *Salamanders and Newts.*—These are primitive, generalized forms with an elongated body and a persistent tail (Fig. 131). As a rule, two pairs of limbs are present; there are approximately equal in size, but the posterior pair is sometimes wanting. In such forms as *Necturus,* the common mud puppy, the gills are persistent and functional throughout life although small lungs

are also developed. In many other forms the gills are replaced in adult life by functional lungs.

2. *Toads and Frogs.*—In these amphibians the body is short and broad and lacks a tail in the adult stage of development (Fig. 117). Two pairs of limbs are always present, the hind limbs being much larger than the fore limbs. Gills are present only in early life, in all cases being later replaced by functional lungs.

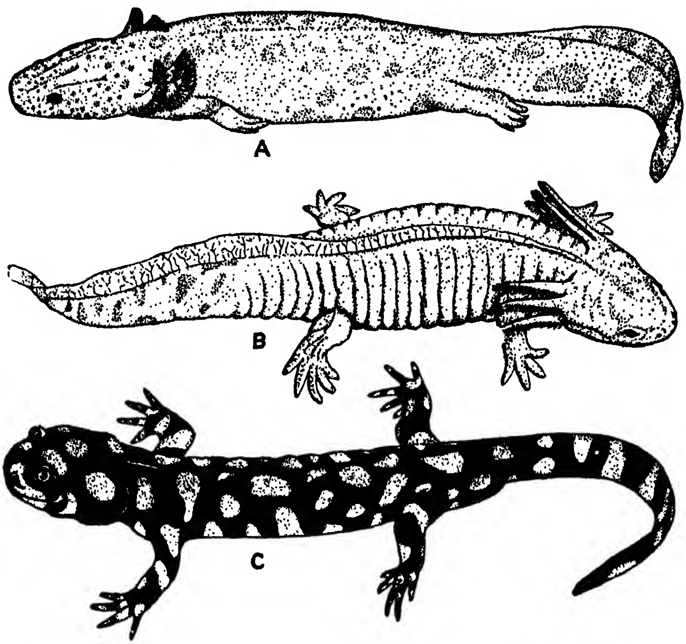


FIG. 131.—Salamanders. *A*, mud puppy (*Necturus maculosus*), × 1/3; *B*, larva and *C*, adult of tiger salamander (*Ambystoma tigrinum*), × 2/3. (*From Wolcott, "Animal Biology."*)

Reptiles.—There are about 4,000 species of living reptiles. Like the two lower classes, reptiles are cold blooded, but show a great advance in being entirely without functional gills at any stage of development. Some members of the group live in water, but all reptiles have functional lungs and so breathe air. In contrast to the amphibians, the skin is covered with scales, hard plates, or both. Nearly all reptiles have four limbs (snakes being a notable exception), and the toes end in claws, as in most of the higher vertebrates. The heart is three chambered, as in the

amphibians, but the ventricle is partially divided. In the crocodiles and alligators, however, the heart is almost completely four chambered. Fertilization is internal without exception, but in most cases shelled eggs are laid, which hatch outside the body. The eggs are always laid on land, even those of aquatic reptiles. Like the amphibians, reptiles have had a long geologic history and were a much more important group in the past than they are today. It is believed that reptiles arose from amphibians long ages ago and later gave rise to both birds and mammals. There are only three main surviving groups:

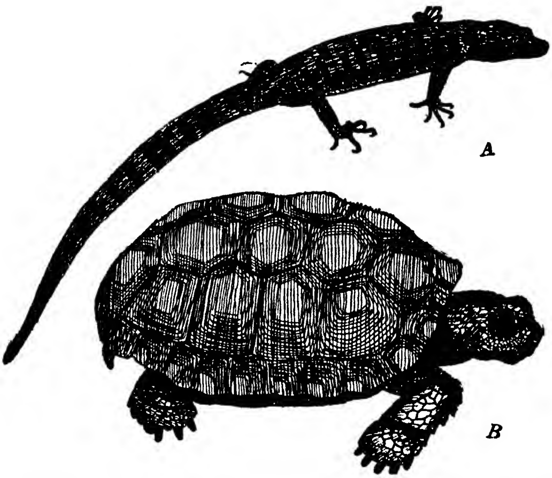


FIG. 132.—Reptiles. *A*, a lizard (*Gerrhonotus scincicauda*), × 1/4; *B*, desert tortoise (*Testudo agassizi*, × 1/5.

1. *Lizards and Snakes.*—These reptiles have an elongated body covered only with scales (Fig. 132*A*). In all snakes and a few lizards, limbs are entirely lacking. Teeth are present.

2. *Turtles and Tortoises.*—These are reptiles with a short body enclosed within a shell consisting of an upper and a lower portion (Fig. 132*B*). The shell is composed of bony plates firmly fastened to the vertebrae and ribs. Scales may be present on other parts of the body. Teeth are absent.

3. *Crocodiles and Alligators.*—The body of these forms is elongated and covered with hard scales that do not overlap; sometimes it is covered also with bony plates. Teeth are present. The heart is almost completely four chambered.

Birds.—The 14,000 species of birds form a very distinct class of vertebrates. Birds are specialized for aerial life (Fig. 133). Like the reptiles, they lack gills at all stages of development, but show an advance in being warm blooded. The skin is covered with feathers, scales occurring only on the feet. Feathers conserve the heat of the body and increase the surface of the wings and tail in flight. In all birds the fore limbs are modified to form wings. The jaws, enclosed by a horny bill, have no teeth. The heart is completely four chambered. Fertilization is internal, as in reptiles. All birds lay shelled eggs, which hatch outside the body. A special feature of the group is the presence

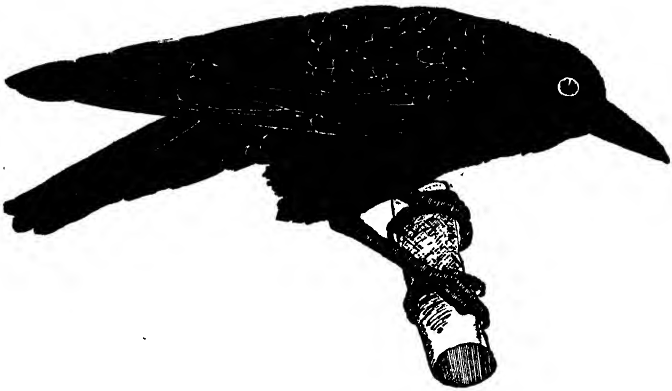


FIG. 133.—Crow (*Corvus brachyrhynchos*, × 1/5.

of air spaces among the internal organs and often inside the bones as well. Birds are closely related to the reptiles and were derived from them during middle geologic time. The orders of modern birds are so numerous that only some of them can be briefly mentioned here.

1. *Diving Birds.*—The loons, grebes, auks, and penguins are diving birds with short wings and webbed or lobed toes (Fig. 207*C*). The legs are placed far back on the body, so that a more or less erect attitude is maintained on land.

2. *Long-winged Swimmers.*—The gulls and terns are long-winged water birds with sharp-pointed or hooked beaks and webbed toes. They live mostly on fishes.

3. *Anserine Birds.*—The ducks, geese, and swans are also swimming birds with webbed toes (Fig. 207*B*). The beak is

flattened and often furnished with tooth-like projections that act as strainers for food.

4. *Shore Birds.*—The snipes, sandpipers, plovers, stilts, avocets, etc., are small or medium-sized birds common along the margins of streams and lakes (Fig. 207*A*). They have long slender legs adapted for wading and an elongated beak used in getting food from mud. The toes are long, slender, and more or less lobed.

5. *Gallinaceous Birds.*—These are scratching birds, including grouse, quail, partridges, pheasants, turkeys, and domestic fowls (Fig. 206*A*). The toes are short and stout, the hind one being lifted above the ground. These birds have short, stout, convex bills adapted for crushing seeds.

6. *Raptorial Birds.*—This order comprises the birds of prey, such as hawks, eagles, vultures, and owls (Fig. 206*B*). The powerful clawed feet are adapted for seizing living prey, the stout, strong, hooked beak for tearing flesh. The vultures live on carrion.

7. *Woodpeckers.*—The woodpeckers and flickers are climbing birds having sharp-clawed toes usually arranged with two in front and two behind (Fig. 206*C*). The bill is straight, pointed, and very stout, being used for digging into bark and wood for insects.

8. *Passerine Birds.*—This order includes approximately half of all known species of birds. They are of small or medium size and have four webless toes of equal length arranged on the same level with three in front and one behind (Figs. 133, and 206*D* and *E*). They are also known as "perching birds" and include all our common songsters, examples being the flycatchers, warblers, crows, blackbirds, finches, swallows, sparrows, wrens, thrushes, and many others.

Mammals.—The highest group of vertebrates numbers about 5,000 species. Like the birds, mammals are warm blooded and at no time have gills. The skin is covered with hair, which may be reduced in area or nearly wanting (Fig. 134). Two pairs of limbs are nearly always present. The heart is completely four chambered. Fertilization is internal, and in almost all mammals the young undergo their early development within the mother's body. A distinctive feature of the group is the fact that the young are nourished by milk secreted by the *mammary glands* of the female.

The development of the brain far surpasses that seen in any of the lower groups. In most cases the teeth develop in two sets and are differentiated into four distinct types. Mammals originated from reptiles in middle geologic time or somewhat earlier but did not reach their greatest development until within relatively recent times. The more important mammalian groups are presented below:

1. *Monotremes.*—The monotremes are the most primitive of existing mammals. The duckbill and spiny anteater of Australia and adjacent islands are the only surviving representatives (Fig. 163). These curious forms lay shelled eggs like those of reptiles

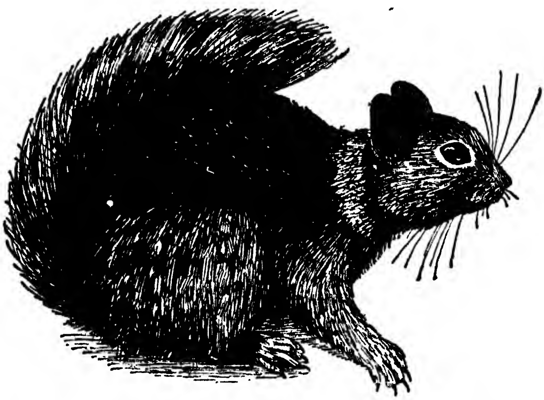


FIG. 134.—Ground squirrel (*Citellus beecheyi*), × ⅓.

and birds. They are also characterized by a cloaca and by the fact that the mammary glands are not localized.

2. *Marsupials.*—The marsupials comprise the kangaroo and its many Australian relatives, and the opossums of America. The young are born in a very immature state and are placed within an abdominal pouch called the *marsupium*, inside of which are the mammary glands.

3. *Insectivores.*—These are the most primitive of the *placental mammals* (see p. 240) and include the shrews, moles, and hedgehogs (Figs. 208 and 215). They are small creatures that eat insects and other small animals. Their teeth are small and simple. Many of the insectivores are burrowing in their habits.

4. *Bats.*—The bats are the only mammals that really fly. A large web extends between the greatly lengthened digits of

the fore limb, reaching to the sides of the body and to the hind limbs, forming a wing (Fig. 217). The simple teeth are adapted to a diet consisting of fruit or of insects. The vampire bats of South America bite into the skin of the victim and lick up the exuding blood.

5. *Carnivores.*—These are the flesh-eating mammals. Bears, dogs, cats, weasels, otters, raccoons, skunks, and badgers are well-known forms, while the seals, sea lions, and walruses are marine representatives (Fig. 216). The teeth of carnivores are adapted for tearing and cutting flesh (Fig. 211).

6. *Rodents.*—The rodents are small mammals but exceed all the other groups in number of species. They include the rats, mice, guinea pigs, squirrels, prairie dogs, gophers, beavers, hares, rabbits, porcupines, etc. For the most part rodents eat plant food, their teeth being adapted for gnawing (Figs. 134 and 210).

7. *Edentates.*—This order includes mammals characterized by an absence or imperfect development of teeth, such as the sloths, armadillos, hairy anteaters, and scaly anteaters.

8. *Ungulates.*—These are the hoofed mammals, which walk on the tips of their toes (Fig. 213*C*). The even-toed ungulates (artiodactyls) include the cattle, sheep, goats, antelopes, deer, elk, giraffes, camels, hippopotamuses, and hogs. The horses, tapirs, and rhinoceroses are odd-toed ungulates (perissodactyls). The teeth of ungulates are adapted to plant food (Fig. 212).

9. *Elephants.*—There are only two living species of elephants, one native of Africa, the other of India. The feet have five functional toes and each toe is hoofed. The nose is developed as a prehensile trunk, and the two front teeth as tusks.

10. *Sirenians.*—This group includes the manatees or sea cows of the Atlantic Coast of America and Africa, and the dugongs of Australia, the Indian Ocean, and the Red Sea. They are sluggish aquatic mammals living along seacoasts and feeding upon plants. The hind limbs are absent, while the fore limbs and rounded tail are paddle-like.

11. *Cetaceans.*—This is also an aquatic order, comprising the whales, dolphins, and porpoises (Fig. 218*C*). As in the last group, the hind limbs are wanting, the fore limbs and tail being paddle-like. Hair is almost completely absent. Some cetaceans have teeth, but in others teeth are replaced by "whalebone." The whales are the largest living mammals.

12. *Primates.*—The primates, comprising the lemurs, monkeys, apes, and man are entitled to first place in the animal kingdom only on the basis of their mental development. Physically they are simpler than most of the other mammalian groups. Primates are prevailingly arboreal forms with relatively primitive teeth and limbs (Figs. 209 and 213*A*). The digits have nails rather than claws or hoofs.

CHAPTER XI

CHIEF ANIMAL TISSUES

A *tissue* is a group of similarly differentiated cells performing one or more functions in common. It may consist only of cells, or of cells and products derived from them. The sponges and coelenterates are characterized by relatively simple tissues, but in members of the higher metazoan groups complex tissues of a number of different kinds are present, all of which arise from undifferentiated cells of the embryo. With the exception of the reproductive cells, all the tissues of the body of the higher animals may be referred to four main types: epithelium, muscle tissue, nerve tissue, and connective and supporting tissues. Each of these will be briefly considered.

Epithelium.—This is always a relatively simple type of tissue that covers the external and internal surfaces of organs and forms the secreting cells of glands. It includes the outer part of the skin (epidermis) and the lining of the various internal cavities and tubes. Its cells are relatively small, regular, and compactly arranged. In the sponges and coelenterates the body is composed almost entirely of epithelial cells, most of which are but slightly specialized. In more complex metazoans, on the other hand, various types of epithelia are present, which may be somewhat modified in accordance with the functions they perform, such as protection, absorption, secretion, etc. Epithelial cells may be either flat, cubical, or columnar, and are often ciliated (Fig. 135). Epithelium commonly consists of a single layer of cells, but often, as in the outer portion of the human skin, it is stratified, comprising many layers.

Mucous membranes, which consist of epithelial tissue, line the respiratory and alimentary tracts. They secrete a sticky substance called *mucus*. The mucous membrane of the respiratory passages is composed of a single layer of columnar epithelial cells with cilia. The beating of the cilia tends to sweep bacteria and other foreign bodies out of the air passages. The mucous mem-

brane that lines the alimentary canal consists of stratified epithelium. The mucus secreted by it serves as a lubricant, facilitating the onward movement of food. *Serous membranes* line the cavities that do not communicate with the surface of the body. They also cover the organs lying within and serve as a means of attachment for them. For example, the *pleurae* line the thoracic cavity and cover the lungs, the *peritoneum* lines the

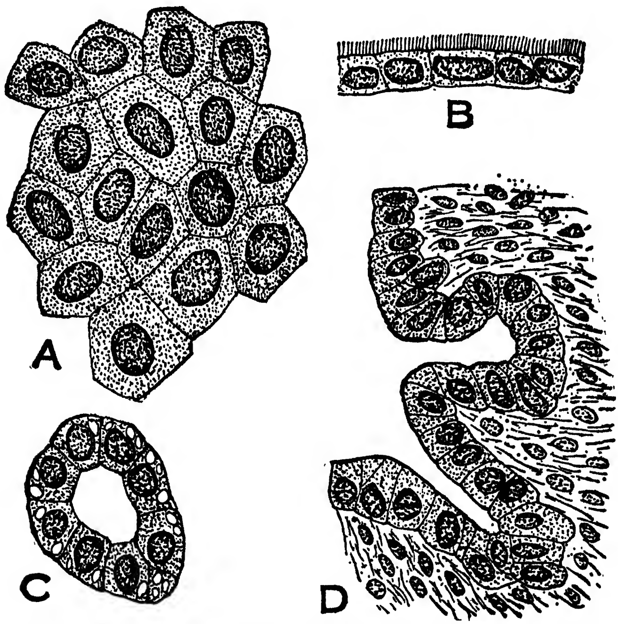


FIG. 135.—Several types of epithelial tissue from larval salamander, × 300. *A*, surface view of flat epithelium from skin; *B*, ciliated epithelium from pharynx; *C*, cubical epithelium from kidney tubule; *D*, columnar epithelium from intestine. (*From Wieman, "General Zoology."*)

abdominal cavity and covers the abdominal organs, while the *pericardium* forms a covering for the heart.

Glands are composed chiefly of modified epithelium and secrete substances of various kinds. Examples are the sweat glands and oil glands of the skin, and the glands of the stomach, pancreas, and small intestine. The simplest glands are one-celled structures, abundant in invertebrates and represented in man by the scattered *goblet cells* that occur in the mucous membrane lining the stomach and intestines (Fig. 136). The various other

glands are many celled and form depressions lined with epithelium. They may be cup-like, flask-shaped, or tubular and may be either branched or unbranched. A branched gland is said to be *compound*, an unbranched one *simple*. The secretion is poured into the cavity of the gland, usually leaving the gland cells intact. In oil glands and milk glands, however, the secreting

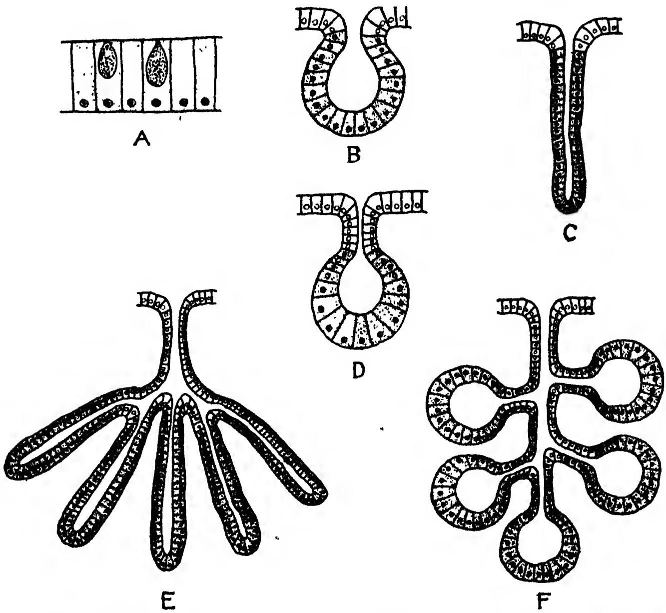


FIG. 136.—Diagram showing types of glands. *A*, goblet cells; *B*, simple saccular gland; *C*, simple tubular gland; *D*, simple alveolar gland; *E*, compound tubular gland; *F*, compound saccular gland. The secreting portions of the glands are stippled.

cells are broken down and pass out of the gland with their product; they are replaced by newly formed cells.

Nails, claws, hoofs, and horns are composed of compact layers of epithelial cells that have become greatly hardened with a substance called *keratin*.

Muscle Tissue.—Muscle is composed of cells that are specialized for contraction (Fig. 137). There are two kinds of muscle: *smooth* and *striated*. Smooth muscle consists of layers of elongated, uninucleate cells pointed at either end. They compose the muscles of most of the lower animals and nearly all the involuntary muscles of the higher animals, such as those of the walls of

the digestive tract, trachea, bronchial tubes, bladder, uterus, blood vessels, and of certain glands and their ducts. Voluntary muscles, which are those under the control of the will, are striated. They are made up of bundles of long fibers with numerous transverse striations, each fiber representing a row of cells that have fused together. Scattered nuclei occur at intervals along the fiber. Each fiber is surrounded by a firm membranous sheath, while each bundle of fibers is enclosed by a layer of connective tissue. Striated muscle is highly specialized and capable of much

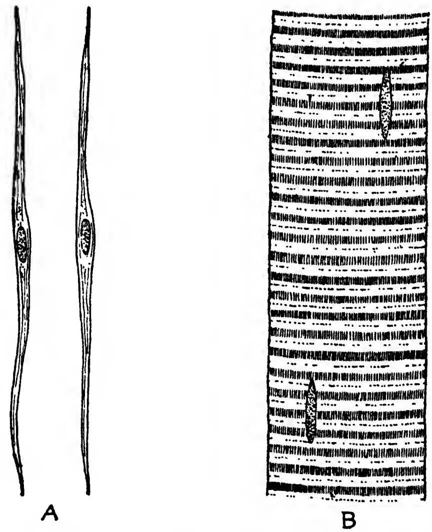


Fig. 137.—Muscle tissue. *A*, smooth muscle cells; *B*, part of a striated muscle fiber, with two nuclei.

greater and more rapid contraction than smooth muscle. The muscle tissue that forms the wall of the heart is of a special type in that, although striated, it is involuntary.

Nerve Tissue.—This kind of tissue is also highly specialized. Its functions are to receive and conduct sensations and to stimulate activity in other cells. A nerve cell consists of a nucleated *cell body* from which extend thread-like cytoplasmic fibers that carry the nervous impulses (Fig. 138). The fibers of each nerve cell are nearly always of two kinds: *dendrites*, which normally carry impulses toward the cell body, and an *axon*, which carries them away. Generally the dendrites are relatively short and

branched, while the axon is very long and branched only near its tip. A nerve cell with its fibers is called a *neuron*. A *ganglion* is an aggregation of cell bodies, while a *nerve* is a bundle of nerve fibers. Some nerve fibers have a sheath of fatty material and are said to be *medullated*, while those which lack a sheath are *non-medullated*. Most nerves are surrounded by a sheath of connective tissue.

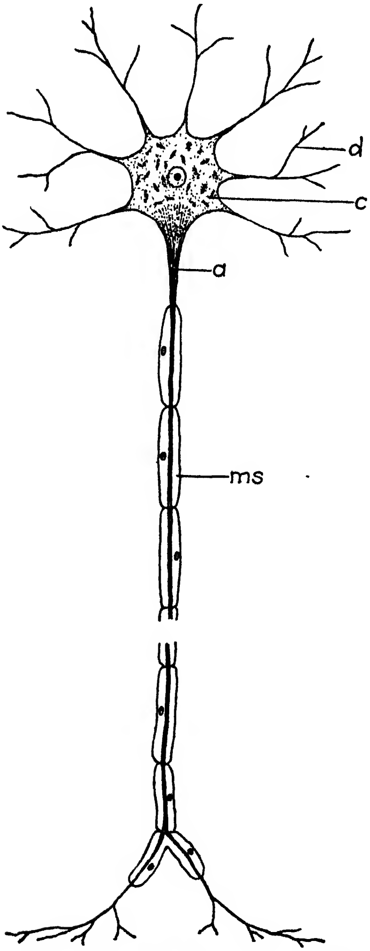


FIG. 138.—Diagram of a typical neuron; *c*, cell body; *d*, dendrite; *a*, axon; *ms*, medullary sheath.

Connective and Supporting Tissues.—These include a variety of tissues whose function is to bind together various parts of the body or to give rigidity and support. They include fibrous tissue, cartilage, bone, blood, etc. All these tissues are characterized by the presence of some kind of intercellular substance that is mostly non-living itself but is nearly always formed as a secretion from the living cells. Consequently the cells are embedded in a matrix (or a fluid, in the case of blood), but are themselves little specialized. The matrix, rather than the living cells, determines the character and functions of the tissue.

White fibrous connective tissue is non-elastic. It consists of rows of flattened cells distributed throughout a gelatinous matrix containing delicate white fibers. The fibers may occur singly or in bundles and are unbranched. White fibrous tissue is tough and flexible. It is found in many parts of the body. It forms the tendons and ligaments, as well as the cover-

ings of muscles. Tendons serve to attach muscles to bones, while ligaments are bands that hold bones together.

Yellow fibrous connective tissue is made up chiefly of many elastic fibers. They usually occur singly, but branch extensively and tend to form a network. Elastic tissue is found throughout the body, especially in the walls of arteries and in the walls of the lungs. It also occurs as shock-absorbing pads between the vertebrae.

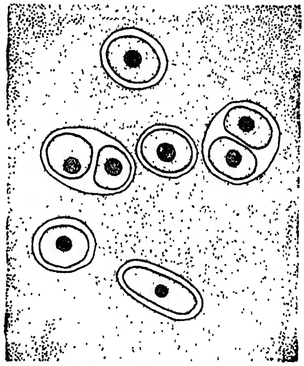


FIG. 139.—Section of hyaline cartilage, showing the cells imbedded in a non-living matrix, × 500.

Fatty (or *adipose*) *tissue* consists of cells containing large globules of fat and surrounded by a matrix of white fibers and a few elastic fibers. The cells are numerous and crowded together. Fatty tissue is abundant in bone marrow. It also occurs in layers in the deeper parts of the skin and around various internal organs.

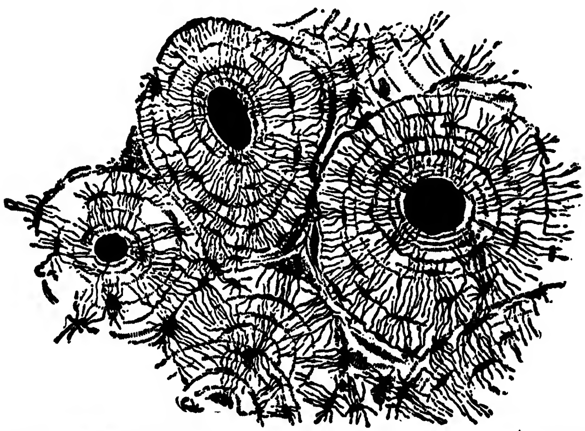


FIG. 140.—Cross section of bone, the intercellular substance in white. The large black areas are occupied by blood vessels, the bone cells lying in the smaller spaces arranged in concentric circles, × 150. *(From Schäfer "Textbook of Microscopic Anatomy," Longmans, Green & Company, after Sharpey, by permission.)*

Cartilage may be either fibrous or hyaline, depending on the character of the matrix surrounding the cells. If fibrous, the fibers may be either white or yellow. Hyaline cartilage has a

clear matrix apparently without any fibers but actually with very small ones. The cartilage cells occupy small spaces in the matrix, each space containing one or several cells (Fig. 139). Cartilage is firm and tough. It covers the ends of bones, joins certain bones together, and forms the supporting tissue for the nose, ear, larynx, trachea, and bronchial tubes.

Bone is the chief supporting tissue of vertebrate animals. It is composed of cells that secrete a hard matrix of mineral matter, consisting chiefly of lime and phosphorus, which is generally laid down in the form of thin concentric layers (Fig. 140). Human

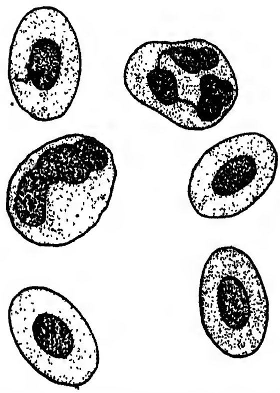


FIG. 141.—Blood corpuscles of a frog, four of them red and two white, × 750.

bone consists of about 58 per cent calcium phosphate, 7 per cent calcium carbonate, and 33 per cent organic matter. The bone cells lie in small cavities connected with one another by delicate cytoplasmic strands that penetrate the matrix. The small cavities containing the bone cells are arranged in concentric circles that surround larger canals occupied by blood vessels, connective tissue, and fat cells. The bone is surrounded by a connective-tissue membrane that supplies it with nerves and blood vessels. The shafts of long bones contain a marrow cavity.

Blood consists of cells that float freely in a liquid, but unlike other connective tissues the intercellular substance is not produced by the cells. The three principal constituents of the blood of vertebrates are the liquid *plasma*, the *red corpuscles*, and the *white corpuscles* (Fig. 141).

CHAPTER XII

METABOLISM IN ANIMALS

Through our study of plants we have become acquainted with a number of aspects of metabolism that are fundamental to all living things (see Chap. VII). We have learned what food is and how it is formed in green plants. We have seen that all organisms use the same kinds of foods—carbohydrates, fats, and proteins—and that these are utilized by both plants and animals in exactly the same ways, *viz.*, in the building up of body substance (both protoplasm and its derivatives) and as a source of energy. We have seen that the processes of digestion, assimilation, respiration, and their accompanying energy relations are essentially similar in both plants and animals. Therefore our present interest is not so much in the nature of these metabolic processes as in the ways in which they are carried on in animal bodies, especially in those of the higher animals.

The distinctive feature of nutrition in animals is their inability to carry on photosynthesis and their consequent dependence for energy and formative material, either directly or indirectly, upon food previously made by green plants. For this reason most of the ordinary activities of animals are concerned primarily with the procuring and utilization of food, necessitating in most cases the development of special prehensile organs, of special sense organs, of complex digestive and excretory organs, of a means of locomotion, and of many other complexities in organization and behavior that green plants do not have. Because animals are active and perform their functions in a more accelerated manner than plants, they have a much higher rate of metabolism, expending a vastly greater amount of energy, and demanding a correspondingly larger consumption of food. In fact, the greater part of the food consumed by animals is used to replenish energy expended in muscular movements.

Feeding Habits.—Animals show great variability with respect to the kinds of materials upon which they feed and to their

means of obtaining their food. Man is *omnivorous*, using foods that come from many different sources, but the diet of most animals is restricted to a few types, or to only one type, of food. *Herbivorous* animals feed upon plants, while *carnivorous* forms eat animal food. Some carnivores, such as hawks and wolves, are *predatory*, capturing living animals and devouring them; others are *scavengers*, eating carrion, examples being vultures and hyenas. Some animals live on plant or animal products, such as nectar, dead leaves, dung, etc. *Parasites* attach themselves to and extract nourishment from other living animals, living either on the outside of the body, as fleas and lice, or inside, as tapeworms.

Dietary Requirements.—Since carbohydrates, fats, and proteins furnish the only sources of energy that animals utilize, properly speaking, these are their only true food substances. Because fats contain relatively less oxygen than do carbohydrates, they are capable of undergoing greater oxidation and so yield more energy. Proteins, when oxidized in the body, yield the same amount of energy as carbohydrates.[1] They are of greatest value in the building up of tissues and for this purpose are indispensable. When digested, proteins are broken down into amino acids, which are then rebuilt into new proteins and incorporated into the body. The chief sources of carbohydrates in the human diet are potatoes, bread, cereals, milk, and sugar. Fats are obtained chiefly from fatty meat, milk (especially cream and butter), eggs, and salad oils. Foods rich in proteins include lean meat, milk, eggs, whole-grain cereals, peas, and beans. A well-balanced diet would include the three main classes of food substances, based on weight, in about the following proportions: carbohydrates, 65 per cent; fats, 20 per cent; proteins, 15 per cent.

In addition to carbohydrates, fats, and proteins, animals require for normal growth and proper functioning of the body adequate quantities of certain accessory food materials. These are water, inorganic salts, and vitamins. Water is not only an essential constituent of protoplasm but a necessary solvent and a medium in which chemical reactions may be carried on. Water constitutes about 65 per cent of the weight of the human body.

[1] The heat produced by fats, when oxidized in the body, is equal to 9 calories per gram, while carbohydrates and proteins yield only 4 calories.

Mineral salts are essential to the development of bones and teeth, to the regulation of nervous activity and the control of muscular contractions, as constituents of certain digestive juices, in the prevention of an acid condition of the tissues, etc. Salts are constituents of most foods, particularly of milk, vegetables, and fruits.

Vitamins.—*Vitamins* are organic substances present in many foods of both vegetable and animal origin, very small amounts of which are necessary to the normal functioning of the body. At the present time six different kinds of vitamins are recognized. An insufficient quantity of any one of these in a diet that is otherwise adequate causes marked functional disturbances. It is particularly important to the maintenance of health and the proper growth of infants and children that their diet contain the necessary vitamins in sufficient amounts. Xerophthalmia, beriberi, scurvy, rickets, and pellagra are definitely known to result from a lack of specific vitamins and so are appropriately termed "deficiency diseases." Each of these can be entirely prevented or effectively cured by eating foods containing enough of the proper vitamins.

Although some foods are deficient in vitamins, as to both variety and quantity, especially meats, potatoes, and white bread, an adequate supply of each of the necessary vitamins will be obtained if the diet is sufficiently diversified to include whole-grain cereals, dairy products, eggs, vegetables, and fruits. Most of our knowledge of vitamins has been obtained in recent years, and today much progress is being made toward a determination of the exact role that each plays in human metabolism. Some of the vitamins have been isolated in pure chemical form, and at least four have been synthesized. The six different vitamins have been designated by letters. Vitamins A, D, and E are soluble in fats; vitamins B, C, and G are soluble in water.

Vitamin A.—This vitamin is derived from carotin ($C_{40}H_{56}$), a substance present in all green plants as a constituent of chlorophyll. It also occurs in many orange or yellow vegetables and fruits. When plant food containing carotin is eaten by animals, the carotin is converted in the liver to vitamin A ($C_{20}H_{30}O$). Foods rich in carotin or in vitamin A include butterfat, egg yolk, liver, cod-liver oil, carrots, sweet potatoes, winter squash, apricots, and all green vegetables. An insufficiency of vitamin A

in the body causes abnormal changes in the respiratory and digestive tracts, susceptibility to infections, retardation of growth, night blindness, and an eye disease called *xerophthalmia.*

Vitamin B.—A substance identified as thiamine ($C_{12}H_{18}N_4OS$), and often designated as vitamin B_1, is especially abundant in yeast, grain hulls, wheat germ, peanuts, milk, eggs, and many fruits and vegetables. It is deficient in artificially refined foods, such as white flour, polished rice, and hominy. Retarded growth, loss of appetite and weight, digestive disorders, and a disease of the nervous system known as *beriberi* result from a deficiency of vitamin B in the diet. Beriberi occurs chiefly among Oriental people whose food consists largely of polished rice.

Vitamin C.—This vitamin, which is cevitamic acid ($C_6H_8O_6$), is abundant in oranges and other citrus fruits, as well as in certain vegetables, such as tomatoes, parsnips, spinach, and cabbage. It is also present in unpasteurized milk. Vitamin C is destroyed to a considerable extent by heating in the presence of oxygen, but this is avoided in commercial canning operations. A deficient amount of this vitamin in the diet causes *scurvy,* a disease characterized by weakness, bleeding, tender gums, and loose teeth. It was once common among sailors whose diet was lacking in fruits and vegetables. Tooth decay and certain gum infections may be due to vitamin-C deficiency, but this has not been established.

Vitamin D.—This is a term applied to one or more substances that enable the body to utilize calcium and phosphorus properly. One of its forms is viosterol ($C_{28}H_{43}OH$), a substance produced when ergosterol is exposed to ultraviolet radiation. Ergosterol is present in many fat-containing foods which, when irradiated, furnish an important source of vitamin D. Foods rich in this vitamin include cod-liver oil, egg yolk, liver, irradiated milk, and irradiated yeast. When the skin is exposed to ultraviolet light, either from the sun or from an artificial source, vitamin D is formed within the body. *Rickets* in infants and young children is a manifestation of faulty calcium and phosphorus metabolism. It is characterized by defective bone structure. Vitamin D prevents and corrects this disease. It is also important in tooth formation and in maintaining a sound tooth structure, although there is no convincing evidence that an adequate amount of vitamin D in the diet will prevent tooth decay.

Vitamin E.—A vitamin present in wheat germ and in lettuce is essential to rats for successful reproduction, but its need in the human diet has not been established. Its absence may be responsible for infertility, at least in some cases.

Vitamin G.—There is some confusion in regard to the identity of this vitamin, which is often designated as vitamin B_2. It appears to be the same as lactoflavin ($C_{17}H_{20}N_4O_6$), a substance occurring in fairly high concentration in whole-grain cereals, milk, eggs, liver, yeast, and green leafy vegetables. A deficiency of vitamin G results in retarded growth and impaired health. *Pellagra* is a disease characterized by skin lesions, digestive disturbances, and nervous disorders. It is of dietary origin and may be prevented by a vitamin present in wheat germ, yeast, and liver. There is considerable uncertainty as to the identity of the pellagra-preventing factor, although it has been supposed by some to be vitamin G.

Digestion.—The purpose of digestion is to render foods capable of being absorbed and ultimately assimilated by living tissues. Some of the foods taken into the animal body, such as simple sugars, can be absorbed directly, but most nutritive materials must undergo chemical change before they can be utilized. Complex foods, most of which are insoluble, must be broken down into simpler substances that can pass into solution. As in plants, digestion in animals is accomplished by *enzymes*, substances of unknown chemical composition that the organism itself produces. In the protozoans and sponges, and to a certain extent in the coelenterates and flatworms, digestion is *intracellular;* that is, it is carried on inside individual cells, each cell engulfing its own food. The coelenterates and flatworms also carry on *extracellular* digestion, and this is the method characteristic of all the higher groups. Here food enters and is digested within a distinct digestive cavity. Enzymes are secreted into the cavity, either by the surrounding cells, or by accessory digestive glands connected with it by ducts.

In all animals except the protozoans, sponges, coelenterates, and a few parasitic forms belonging to the higher groups, a definite digestive system is present. That of a number of different animals has been described in previous chapters. The digestive system of man and other vertebrates consists of a mouth, esophagus, stomach, small intestine, and large intestine.

These organs form a continuous tube, the alimentary canal, to which are attached two main accessory digestive glands, the liver and pancreas.

Human Digestive System.—The lips, teeth, and tongue are used in taking food into the mouth and in preparing it for swallowing. Man has, in the adult set, 32 teeth, there being in each jaw 4 *incisors*, 2 *canines*, 4 *premolars*, and 6 *molars*. The molars, which are broad and flat, and the premolars, of similar form but smaller, are used for grinding food. The canines, or eyeteeth, are conical and are used for biting and tearing, while the chisel-shaped incisors are adapted for biting and cutting. A tooth consists of a *crown*, *neck*, and *root* (Fig. 142). The crown is the portion projecting beyond the gum, the neck the part lying in the gum, and the root the basal portion lying in the jawbone. The crown is covered with *enamel* and the root with *cement*, both of which are very hard. The greater part of the tooth is made of *dentine*, a substance softer than enamel. In the center is the *pulp cavity* containing nerves and blood vessels.

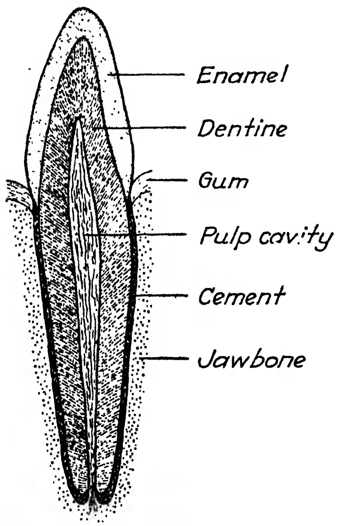


FIG. 142.—Diagrammatic longitudinal section of a human tooth.

The mouth leads into the pharynx, or throat cavity, which is connected with the stomach by means of the long tubular esophagus (Fig. 143). The stomach is a muscular sac about 11 inches long and with a normal capacity of about one to one and a half quarts. It lies just beneath the diaphragm, extending transversely across the body from left to right. The small intestine arises at the lower end of the stomach. It is a narrow, highly coiled tube about 23 feet in length. A duct coming from the liver joins the pancreatic duct near its lower end to form a common duct that enters the small intestine at a point about 4 inches beyond its origin at the end of the stomach. The duct of the liver has a branch, the bile duct, which leads to the gall bladder, a sac in which bile is temporarily stored. The lower

end of the small intestine opens into the large intestine a short distance from its end, leaving a blind sac, the *caecum,* to which is attached the slender *vermiform appendix.*

The large intestine, of greater diameter than the small intestine, is about 5 feet long. It first passes upward, then across the body from left to right just beneath the stomach, extends downward, and finally, after making an S-shaped curve, continues as a straight short tube to the anus. The different parts of the large

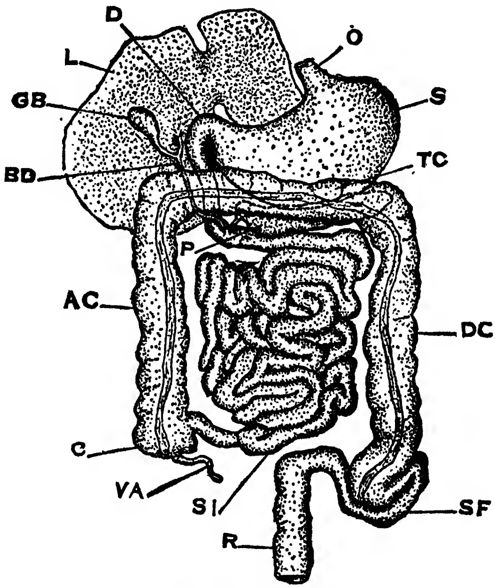


FIG. 143.—Diagram of the human digestive system. *O*, end of esophagus; *S*, stomach; *D*, duodenum (beginning of small intestine); *SI*, small intestine; *VA*, vermiform appendix; *C*, caecum; *SF*, sigmoid flexure; *R*, rectum; *L*, liver; *GB*, gall bladder; *BD*, bile duct; *P*, pancreas. (*From Wieman,* "*General Zoology.*")

intestine, in the order described, are the *ascending colon, transverse colon, descending colon, sigmoid flexure,* and *rectum.*

Digestion in Man.—The more important aspects of human digestion will serve to illustrate the way in which digestion is carried on in the higher animals. The process begins in the mouth, where the food is broken up by chewing and is mixed with *saliva,* a secretion from the salivary glands, of which three pairs are present. These glands are not in the mouth, but lie near it and are connected with the mouth by ducts. Saliva contains mucus, which serves as a lubricant, and an enzyme,

called *ptyalin,* which acts upon starch, gradually converting it to malt sugar. Because food remains in the mouth only a short time, little digestion occurs there. The principal value of chewing is to reduce the size of the pieces of food so that fluids in the stomach and intestine can reach them quickly.

In the act of swallowing, the food passes down the esophagus by waves of muscular contraction in its wall. This is termed *peristalsis,* a type of movement displayed also by other parts of the alimentary canal. The food now enters the stomach, where it is temporarily stored, reduced to a semifluid consistency, thoroughly mixed, and partially digested. Innumerable glands in the wall of the stomach produce a secretion called *gastric juice,* that contains about 0.4 per cent hydrochloric acid and two enzymes—*pepsin* and *rennin.* The acid plays no direct part in digestion; it merely serves to activate the gastric enzymes, as they can do their work only in an acid medium. Pepsin acts upon some of the proteins, changing them to peptones and proteoses. The sole function of rennin is to coagulate milk and thus to separate from it the protein casein. There is no digestion of starch in the stomach except from the saliva mixed with the food. However, as ptyalin acts only in a neutral or an alkaline medium, starch digestion soon ceases in the presence of the hydrochloric acid in the gastric juice, especially in the first food to enter an empty stomach. There is also little or no digestion of fats in the stomach.

After the food taken into the stomach has reached the proper degree of fluidity and digestion, it passes by peristaltic waves into the small intestine, at first in smaller, but later in larger amounts. This movement is controlled by a large circular muscle, the *pyloric valve,* situated at the junction of the stomach and intestine. Normally the stomach becomes empty within 4 hours after an ordinary meal has been eaten, the time it remains there depending upon both the nature and quantity of the food eaten. Upon entering the small intestine, the *chyme,* or partially digested food, is acted upon by other enzymes, the chief ones being in the *pancreatic fluid.* These are three in number: *amylopsin,* which converts starch to malt sugar; *trypsin,* which changes proteins, peptones, and proteoses to amino acids; and *steapsin* (or *lipase*), which breaks down fats into glycerin and fatty acids.

As the food leaves the stomach it is acid but is soon neutralized by the pancreatic fluid and bile, both of which are alkaline. This is necessary because the pancreatic and intestinal enzymes act only in a neutral or a slightly alkaline medium. *Bile,* the secretion from the liver, contains no enzymes, but its presence makes conditions favorable for the action of the pancreatic fluid, especially in its digestion of fats. As the food passes through the small intestine, it is also acted upon by several enzymes contained in the *intestinal juice,* a fluid secreted by glands in the intestinal wall. One of these enzymes, called *erepsin,* supplements the action of trypsin in the conversion of peptones and proteoses to amino acids. Three others change complex sugars to simple sugars. Of these, *maltase* acts on malt sugar, *sucrase* on cane sugar, and *lactase* on milk sugar.

The passage of food through the small intestine, brought about by peristalsis, consumes about 4 hours, or slightly longer. Although this is approximately the same length of time that the food may remain in the stomach, nearly all the work of digestion is carried on here in the small intestine, especially in its upper end. The large intestine contains no enzymes. The remaining portion of the food, consisting chiefly of indigestible residue, normally stays in the large intestine about 24 hours, or often longer, before passing out of the body as *feces.* During this time it loses most of its water and undergoes partial decomposition through the activity of bacteria that flourish in the large intestine in enormous numbers. Some of the decomposition products, chiefly sugars arising from the breaking down of carbohydrates not previously digested (such as cellulose), may be absorbed here. Toxic products of decomposition may also be absorbed to some extent if the elimination of fecal matter from the body is considerably delayed.

Absorption.—The absorption of food takes place almost entirely in the small intestine, very little going on in the stomach or in the large intestine. The inner wall of the small intestine is infolded and covered with innumerable small, finger-like projections called *villi,* which greatly increase its absorbing surface. Each villus contains a network of blood capillaries surrounding a central *lacteal,* or lymph capillary (Fig. 144). On the outside is a layer of epithelium containing scattered mucous cells. The digested foods pass into the villi by osmosis.

The products arising from the digestion of carbohydrates and proteins enter the blood stream directly, but the fat derivatives are absorbed by the lymph. There they are recombined into fats, eventually reaching the blood stream by way of the *thoracic duct,* which empties into a vein in the upper thoracic region.

The digested food, taken up by the circulatory system, is eventually carried to all parts of the body to be assimilated by the living tissues. The veins carrying food from the digestive organs come together to form the large *portal vein,* which goes to the liver. Here much of the sugar transported by the blood is converted to an insoluble carbohydrate called *glycogen,* and temporarily stored in this form. Later it is gradually changed back to sugar and transported, as needed, to the tissues. Chemically, glycogen is similar to starch; in fact it is often referred to as "animal starch." Some glycogen is also stored in the muscles. When an excess of food, especially of fats and carbohydrates, is habitually eaten, some of it may be stored permanently in *fatty* or *adipose tissue.* This accumulates in thick layers beneath the skin and around the heart, liver, kidneys, and intestines, often interfering with their normal functions.

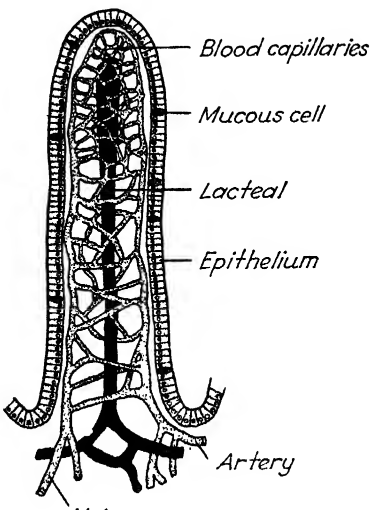


FIG. 144.—Diagram of an intestinal villus of man.

The final step in constructive metabolism is *assimilation*—the transformation of digested food into protoplasm. Food is used both in the building up of protoplasm and as a source of energy. Proteins may serve either purpose, but carbohydrates and fats supply most of the energy required by the animal body. They are especially important as sources of heat.

Respiration.—The breaking down of organic matter in the body to liberate energy has been adequately discussed in connection with plants and need not be repeated here (see Chap. VII). In animals this energy is expended chiefly as mechanical and heat

energy. It has been seen that respiration is essentially the same process in all organisms, always involving the absorption of oxygen by living cells and the liberation of carbon dioxide. In the protozoans and in such simple metazoans as sponges, coelenterates, flatworms, and roundworms, oxygen is absorbed through the surface of the body from the surrounding medium and slowly diffuses inward, while carbon dioxide passes in the opposite direction. The greater structural complexity of the earthworm necessitates the development of a circulatory system for the transportation of the respiratory gases, but no special respiratory organs are present, aeration taking place through the moist outer skin. In the higher animals a respiratory system becomes established, consisting in most cases of either tracheae, gills, or lungs.

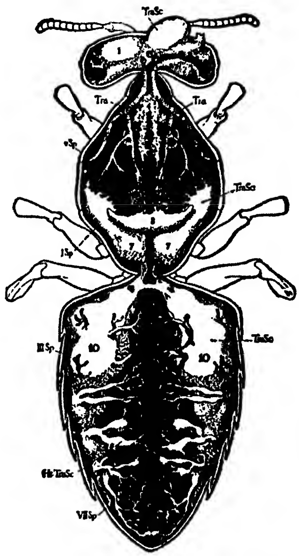


FIG. 145.—Respiratory system of the honeybee. (*From Snodgrass, "Anatomy of the Honeybee."*)

The insects carry on respiration in a unique manner. Their blood carries food but no oxygen or carbon dioxide. Air is brought directly to the cells through a system of *tracheae*—delicate, highly branched tubes that communicate with the atmosphere by means of small openings in the body wall called *spiracles* (Fig. 143). In most of the higher animals, on the other hand, air does not come in direct contact with the tissues. Instead, the gaseous exchange necessary to respiration occurs in either gills or lungs, oxygen being transported from these organs to all parts of the body by the circulatory system. *Gills* are present in most of the aquatic annelids, echinoderms, mollusks, and arthropods, as well as in the fishes and amphibians (at least in the younger stages of the latter). They consist of thin delicate membranes commonly occurring in sheets or in tufts. *Lungs* occur in all air-breathing vertebrates, arising embryonically as pouches from the pharynx. They are spongy organs containing numerous small cavities into which air passes

directly from the atmosphere. Both gills and lungs are richly supplied with capillaries, and it is through their walls that the exchange of respiratory gases takes place. A distinction is often made between *external respiration,* the exchange of gases occurring in the gills or lungs, and *internal respiration,* the gas exchange that goes on in the tissues. In external respiration the blood receives oxygen and liberates carbon dioxide, while in internal respiration it receives carbon dioxide and liberates oxygen.

In man, air is inhaled through the nostrils, goes through the nasal passages to the pharynx, thence into the trachea, and finally through the bronchial tubes into the lungs. The *larynx,* or voice box, containing the vocal cords, forms the upper part of the trachea. The opening from the pharynx into the larynx is termed the *glottis.* So that food will not get into the respiratory tract, the glottis is provided with a lid, the *epiglottis,* which closes during the act of swallowing. The trachea, or windpipe, is a tube that lies in front of the esophagus and passes downward into the thoracic cavity where it gives rise to a pair of bronchial tubes. In the lungs these break up into smaller and smaller branches, which finally terminate in minute thin-walled cavities, called *alveoli* or air sacs. Thousands of these alveoli, surrounded by capillaries, are contained in the lungs. The absorption of oxygen by the blood and the liberation of carbon dioxide take place by osmosis through the delicate walls of the capillaries and of the alveoli.

Air is forced into and out of the lungs by movements of the diaphragm and chest muscles. The *diaphragm,* a feature of all mammals, is a muscular partition separating the thoracic cavity, in which the lungs lie, from the abdominal cavity. When relaxed, the diaphragm is arched upward, but when contracted, it becomes flat and thus enlarges the thoracic cavity. As the diaphragm contracts, the ribs and sternum are pulled outward by the chest muscles, and air rushes into the lungs, causing them to expand. Decrease in the size of the thoracic cavity, brought about by relaxation of the diaphragm and chest muscles, makes possible the contraction of the lungs, thus forcing air out of them. Only about one-sixth of the air in the lungs is renewed with each breath taken. Under ordinary conditions about a pint of air is inhaled and exhaled, approximately two and a half quarts

remaining in the lungs. During violent exertion, however, when the breathing is deeper and more rapid, only about a quart of air is left in the lungs. The inhaled air loses about one-fifth of its oxygen and takes up about an equal amount of carbon dioxide. Since the atmosphere contains approximately 20 per cent of oxygen, the air exhaled from the lungs contains about 16 per cent of oxygen and 4 per cent of carbon dioxide.

Circulation.—The lower animals have no need for a special circulatory fluid. Cells not in direct contact with food or oxygen are close to cells that are and can readily absorb from them these vital necessities. Similarly, waste materials have to move only a short distance to be eliminated. In the coelenterates and flatworms the gastrovascular cavity, so called because it performs the dual functions of digestion and circulation, carries digested food and oxygen directly to all parts of the body.

In animals of greater structural complexity, a special means of transporting digested food, oxygen, and waste materials is required. Thus in the roundworms and echinoderms a colorless circulatory fluid containing amoeboid cells is present in the coelom, while in the annelids, in addition to the coelomic fluid, a closed system of vessels through which blood circulates is developed. Likewise in the mollusks and arthropods a definite vascular system occurs, but in these groups the blood flows from the open ends of vessels into sinuses. Such a circulatory system is designated as an *open system*. The vertebrates, like the annelids, have a *closed system* of circulation, the blood remaining in the vessels throughout its course. Here the transfer of digested food, oxygen, and metabolic wastes takes place through the walls of capillaries. Blood is propelled through its course by one or more contractile vessels or, in the higher animals, by a heart.

Blood.—Blood consists of a liquid *plasma* containing cells called *corpuscles*. The blood of insects is colorless, that of many crustaceans and mollusks is blue, while the blood of other invertebrates and of all vertebrates is red. The color of blood is due to the presence of a pigment present either in the plasma, as in invertebrates, or in the corpuscles, as in vertebrates. Blue blood owes its color to *hemocyanin*, red blood to *hemoglobin*.

The blood cells of vertebrates, suspended in the colorless plasma, are of two kinds: *red corpuscles* and *white corpuscles*.

Only the former contain hemoglobin. The corpuscles and the plasma have different functions. The plasma carries most of the dissolved food to the tissues and removes carbon dioxide and other waste products from them. It consists of about 90 per cent water, and also contains inorganic salts, hormones, antibodies, and *fibrinogen,* a substance that aids in the clotting of the blood.

The red corpuscles are especially concerned with the transportation of oxygen. They are oval or circular, disk-like cells, in man and other mammals being biconcave disks (Fig. 146). In human blood they number about 5,000,000 to the cubic millimeter. When oxygen is taken up by the red corpuscles, it combines loosely with the dark-red hemoglobin to form *oxyhemoglobin,* which is brilliant red. This is an unstable compound that, after giving up its oxygen to the tissues, becomes hemoglobin again. Because the color of blood depends upon the presence or absence of oxygen in it, pure (aerated) blood is bright red, while impure (non-aerated) blood is dark red or slightly purplish. In mammals the red corpuscles lose their nuclei soon after being formed, but in all other vertebrates they remain nucleated (Figs. 141 and 146). Red blood cells do not live long—in man, not to exceed 4 weeks. Hence new ones are constantly being formed, their place of origin being red bone marrow. Dead corpuscles are destroyed in great numbers in the spleen and liver.

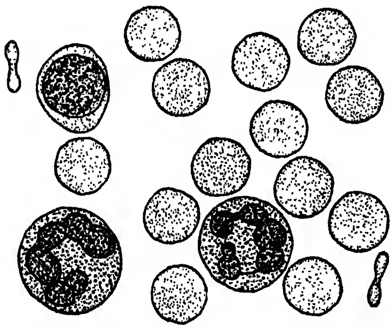


FIG. 146.—Human blood corpuscles, × 1,000. Three white corpuscles are shown. The red corpuscles lack nuclei; two of them are shown in edge view.

The white corpuscles are much less abundant than the red ones, in man numbering from 5,000 to 9,000 to the cubic millimeter. Three principal kinds occur, which differ in size and in the character of their nuclei. In one kind the nucleus consists of several lobes with delicate connections between them. The two largest kinds of white corpuscles exceed the red blood cells in size and may become amoeboid in form, moving by pseudopodia. A peculiar feature of white corpuscles is their ability to pass

through the walls of capillaries into the surrounding tissues. Their function consists partly in engulfing small solid particles, such as bacteria, waste material, and wornout cells, which they destroy by digesting them. They also aid in the transportation of fats to different parts of the body. White corpuscles are attracted to places of injury or infection. In certain types of severe infection, the number of white blood cells increases two or three times. White corpuscles are formed in red bone marrow and in lymph nodes.

Blood platelets, which are constituents only of mammalian blood, are smaller than red corpuscles and colorless. They lack nuclei and are not regarded as cells. Their nature, origin, and functions are not well understood. They seem to assist in the coagulation of the blood. This occurs when blood comes in contact with air or with injured tissue. The fibrinogen of the plasma is converted to threads of *fibrin* that entangle the corpuscles, forming a clot. In so doing, it squeezes out the remaining fluid, which is now designated as *serum*. The clot, in closing the wound, prevents further loss of blood.

Lymph.—In addition to the blood, vertebrates have a colorless fluid derived from it called *lymph*. It occupies intercellular *lymph spaces* and circulates throughout the body in delicate vessels known as *lymphatics*, which are best developed in mammals. Most of these eventually connect with the closed system of blood vessels through the *thoracic duct*, the largest lymphatic. It empties into a vein in the upper thoracic region. Lymph consists mainly of plasma and white corpuscles that have escaped from the blood vessels, as previously noted. Lymph surrounds the living cells of the body and acts as an intermediate medium in the transportation of nourishment and oxygen to them from the blood, and in the removal of waste products. Its function is thus supplementary to that of the blood. *Lymph nodes* are enlargements of lymphatics where white corpuscles are formed and where bacteria that have entered the body are destroyed. *Lymph hearts*, which are contractile organs present in the lower vertebrates but not in mammals, bring about the circulation of lymph throughout the body. This is accomplished in the mammals by pressure resulting from contraction of the muscles.

Excretion.—The breaking down of organic matter in the animal body results in the formation of carbon dioxide, water,

salts, and other metabolic waste products. These are collected by the blood stream and eliminated through the respiratory organs, the skin, and the excretory organs. In mammals nearly all the carbon dioxide is given off through the lungs, while water passes out of the body through the lungs, skin, and kidneys.

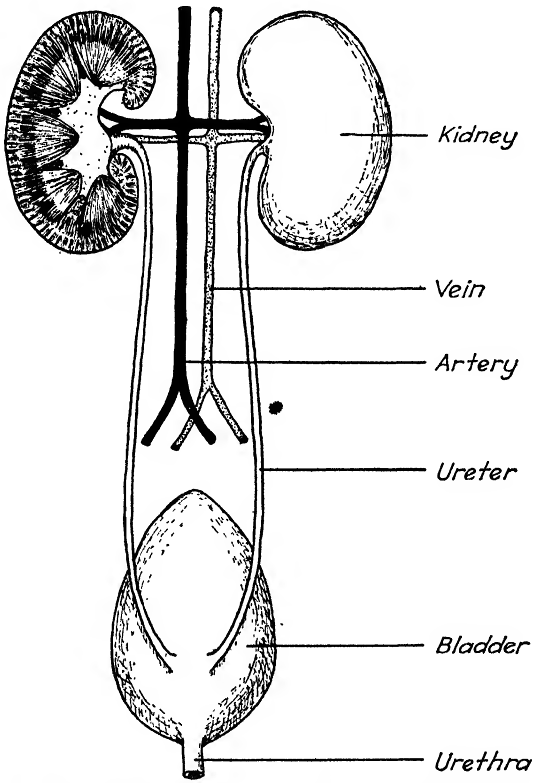


FIG. 147.—Diagram of human excretory system, one of the kidneys shown in longitudinal section.

Nitrogenous waste products, principally urea, always result from the decomposition of proteins and amino acids. In the vertebrates urea is formed chiefly in the liver and is then carried by the blood to the kidneys, where it accumulates. The urea, with a smaller quantity of uric acid, salts, and other waste materials, is dissolved in water to form *urine.* This passes from the kidneys through the ureters to the bladder, where it

is stored before passing out of the body through the urethra (Fig. 147).

In man the kidneys are a pair of bean-shaped bodies situated in the posterior part of the abdominal cavity close to the dorsal body wall. They are composed mainly of a large number of slender complexly branched tubules, each having a terminal capsule that surrounds a network of capillaries. Water with its waste substances passes by osmosis from the capillaries into the

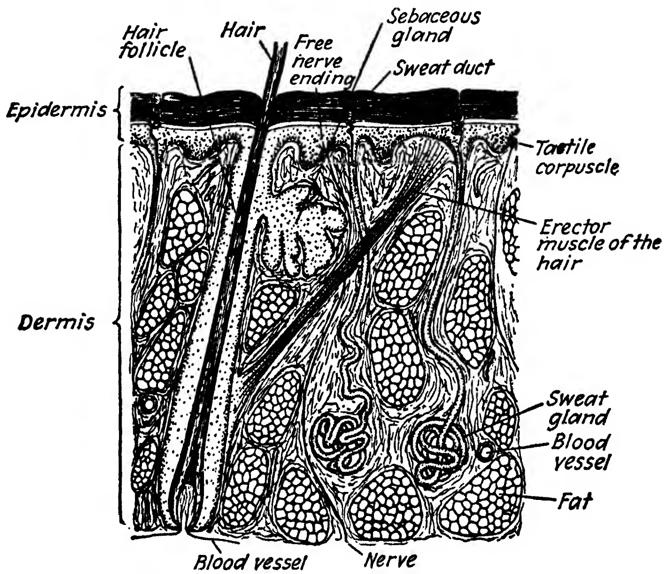


FIG. 148.—Somewhat diagrammatic section of the mammalian skin. (*From Wolcott, "Animal Biology."*)

renal tubules. The tubules lead to larger and larger tubes, which finally converge into the ureter.

The human skin comprises an outer portion, the *epidermis*, and an inner portion, the *dermis* (Fig. 148). The epidermis is composed of stratified epithelium, the dermis of connective tissue. The dermis also contains sensory nerve endings, numerous blood vessels, sweat glands, hair follicles, sebaceous glands, and fat cells. Excretion occurs mainly through the *sweat glands*, each of which is a slender tube opening to the surface by means of a pore. The lower end of the sweat gland is highly coiled and surrounded by a network of capillaries from which water and small quantities of waste products pass. The evaporation of

perspiration leaves a residue of salts and other waste matter on the skin. Sweat glands are stimulated by high temperature, the increased amount of evaporation tending to keep the body cool. Each hair arises at the bottom of a *hair follicle*, a narrow pocket formed by the infolding of the epidermis into the dermis. The follicle is surrounded by *sebaceous glands*, which secrete oil. This softens the hair and skin, and so may be considered a secretion rather than an excretion. Sebaceous glands are present on all parts of the body except the palms of the hands and the soles of the feet.

CHAPTER XIII

COORDINATION IN ANIMALS

Irritability, or the capacity to react to external influences, is a fundamental property of protoplasm and therefore is universal among living things. Although response to stimuli is no more definite in animals than in plants, almost always it is far more rapid and is brought about by a very different mechanism, *viz.*, chiefly through the cooperation of nerves and muscles. In the sponges, the lowest group of metazoans, the cells that react to external influences are stimulated directly, there being no nerve cells. In all the higher animal groups, however, this is not the case. Here differentiated cells are present whose sole function is to receive and conduct stimuli and to bring about responses in other tissues that, for the most part, are themselves incapable of receiving stimuli directly. In the coelenterates, simple nerve cells are present but are not aggregated to form ganglia. In the higher groups, the nervous tissue is organized as an elaborate system of nerves and ganglia, different types of which have already been considered in a number of animals. The nervous system, in controlling the responses of an animal to external influences, makes it possible for various groups of cells to act as a unit. In other words, it directs and coordinates vital functions. Without this controlling influence, there could be no bodily activities.

Nervous System of Man.—Although constructed on the same general plan in all vertebrates, the nervous system reaches its highest degree of organization in man, the brain, in particular, greatly surpassing in relative size and complexity that of any other animal. The *central nervous system* comprises the brain and spinal cord, the *peripheral nervous system* all the nerves arising from them. The brain consists of three main divisions: the *cerebrum*, the *cerebellum*, and the *medulla oblongata* (Fig. 149). The cerebrum is by far the largest division. Its cortex, or outer portion, is composed of *gray matter*, its inner portion of *white*

matter. The amount of gray matter is greatly increased by the development of convolutions, or furrows, which are deeper and more numerous in man than in any other mammal. The cerebellum, lying beneath and behind the cerebrum, is much smaller and only slightly convoluted. The medulla oblongata is a bulbous enlargement situated at the upper end of the spinal cord.

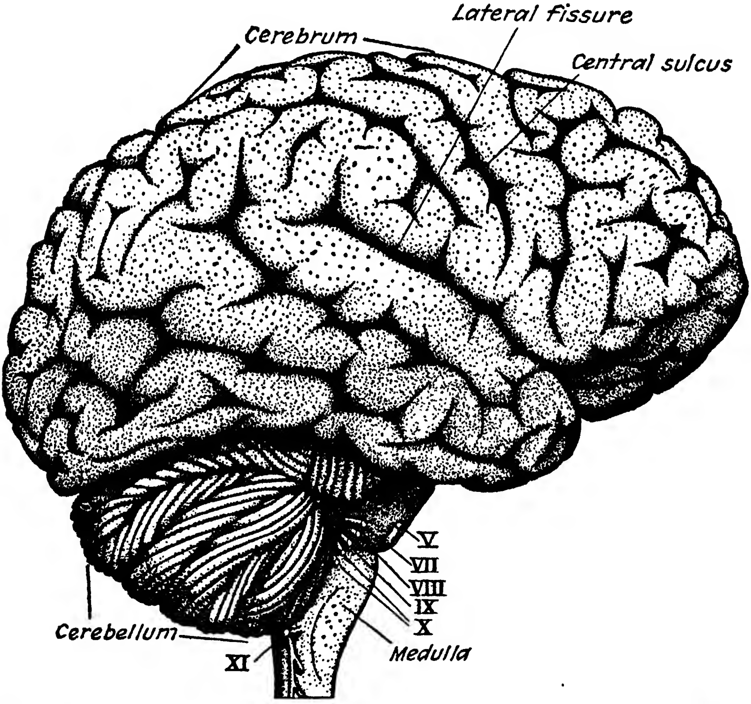


FIG. 149.—Side view of the human brain. The roots of the cranial nerves are indicated by roman numerals. (*From Wolcott, "Animal Biology."*)

In man, 12 pairs of *cranial nerves* arise from the brain. Most of these extend to the sense organs and to other parts of the head, but some go to the neck, shoulders, and organs of respiration, circulation, and digestion.

The spinal cord lies inside the spinal column. It is almost circular in cross section and is nearly divided into symmetrical halves by two deep fissures, one dorsal and the other ventral (Fig. 151). In the center is a very small canal. This is surrounded by gray matter, which extends into each half, through

the outer mass of white matter, to form a dorsal and a ventral horn. As seen in cross section, the gray matter has somewhat the form of the letter H. The *spinal nerves*, of which there are 31 pairs, arise from the spinal cord and pass outward between the vertebrae to supply the lower portions of the body.

The cerebrum is the seat of intelligence, consciousness, memory, and the higher emotions. It controls all voluntary actions. The cerebellum coordinates muscular activity, particularly the movements concerned with equilibrium and locomotion. The medulla oblongata governs such reflex actions as winking, sneezing, and coughing. It regulates the activities of the organs of respiration and of circulation. It also controls the peristaltic movements of the alimentary tract and the secretion of digestive juices. The spinal cord transmits impulses to and from the brain and is the center of reflex actions involving the trunk and limbs.

The *sympathetic nervous system* comprises a number of nerves, ganglia, and *plexuses*, or groups of ganglia, situated in various parts of the body outside the central and peripheral nervous systems. A chain of these ganglia lies on each side of the spinal cord and is connected with branches of the spinal nerves. The cardiac plexus lies just below the heart, the solar plexus behind the stomach. The sympathetic nervous system regulates such involuntary activities as the beating of the heart, the secretion of glands, and the contraction of all involuntary muscles.

Neurons and Nerves.—The *neuron*, or nerve cell, is the structural and functional unit of the nervous system. It consists of a central nucleated portion, the *cell body*, and a number of extremely fine cytoplasmic extensions called *nerve fibers*, which conduct nervous impulses (Fig. 138). The fibers of each neuron are of two kinds, distinguished from each other by the direction in which the impulses are normally conducted by them. *Dendrites* carry impulses toward the cell body, while *axons* carry them away from the cell body. Commonly a neuron possesses a number of relatively short, branched dendrites and a single long axon usually branched only at its tip. Generally the dendrites and the axon extend in opposite directions.

It should be understood that a nerve cell, as a whole, ordinarily can transmit impulses in only one direction. In going from one nerve cell to another, the impulse passes from the terminal branches of the axon of the one neuron to the dendrites of the

other. The fibers of the two neurons are close together but probably not in organic union, the connection between them being termed a *synapse.* A *sensory neuron* carries impulses from a point of stimulation to a nerve center, such as the brain or spinal cord, while a *motor neuron* transmits impulses from a nerve center to a tissue in which a response is to be induced, such as a muscle or a gland. The structure stimulated is called a *receptor,* the one that responds, an *effector.*

In vertebrates, nearly all the cell bodies are in the gray matter of the brain and spinal cord, the others occurring in the

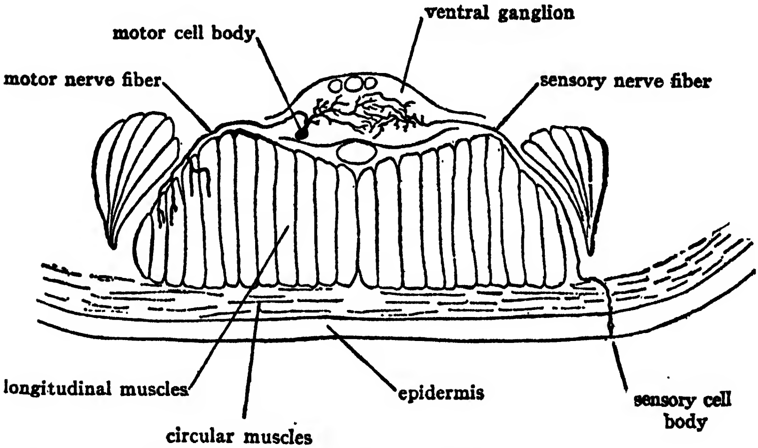


FIG. 150.—Diagrammatic cross section of the ventral nerve cord and surrounding structures of an earthworm. (*From Parker, in Popular Science Monthly, after Retzius.*)

ganglia of the peripheral and sympathetic nervous systems. The white matter of the central nervous system consists chiefly of nerve fibers. *Ganglia* are merely aggregations of cell bodies, while *nerves* are bundles of nerve fibers usually enclosed by a sheath of connective tissue. Thus a nerve fiber is like a wire, a nerve like a cable. A *sensory nerve* consists of the fibers (dendrites) of many sensory neurons, a *motor nerve* of the fibers (axons) of many motor neurons. *Mixed nerves,* on the other hand, are composed of both kinds of fibers, and so are both sensory and motor in function.

Reflex Action.—A *reflex* is a movement or other act resulting from the transmission of an impulse inward from a receptor to a

nerve center and then outward to an effector. It is the simplest type of nervous action. The impulse concerned travels along a path designated as a *reflex arc*. This always involves at least one sensory and one motor neuron. A simple illustration of reflex action may be seen by touching the skin of an earthworm. The mechanism by which a response to this stimulus is brought about may be understood by studying Fig. 150 in connection with the following account.

Lying in the skin of the earthworm are a number of sensory neurons, the dendrites of which receive stimuli acting upon the surface of the body. The axon of each of these neurons passes inward to one of the ganglia of the ventral nerve cord, where its end comes into synapse with the dendrites of one of the many motor neurons of which the ganglion is composed. The axons of certain of these motor neurons pass outward to the muscles of the body wall. Stimulation of the skin causes an impulse to be sent over one or more sensory nerve fibers to the central nervous system. There it is transmitted by one or more motor nerve fibers to a group of muscles that is thereby stimulated to contract. This behavior is called reflex action because the impulse is reflected from the nerve center somewhat as light is reflected by a mirror. *Intermediate neurons*, connecting the sensory neurons stimulated with other motor neurons, may transmit the stimulus to other muscle cells and, as a result of their contraction, the earthworm may crawl away.

Most of the bodily activities of man are brought about by reflex action, and, in such cases, a response to a stimulus is induced without volition. For example, if one's hand accidentally touches a hot object, it is quickly withdrawn before the sensation of pain reaches the brain, because the motor impulse is sent back to the muscles of the arm directly from the spinal cord. The constriction of the pupil of the eye in bright light and its dilation in partial or complete darkness are involuntary responses brought about through reflex action. The acts of sneezing and coughing are reflexes, as are also the secretion of gastric juice, the peristaltic movements of the digestive tract, changes in the rate of beating of the heart, the movements concerned with breathing, shivering when cold, etc. In breathing and similar acts, the stimulus involved arises from within the body instead, as in other reflexes, of coming from outside.

The Spinal Nerves.—In vertebrates, the neurons concerned with most of the reflexes occur in the spinal cord. Sensory nerve fibers lead to it and motor nerve fibers lead from it to the muscles. Each spinal nerve arises from the spinal cord by means of a dorsal and a ventral root (Fig. 151). These spring from the horns of gray matter in the cord. The dorsal root consists of sensory nerve fibers, the ventral root of motor nerve fibers. The cell bodies of all sensory neurons entering the spinal cord lie in a ganglion that forms a slight swelling near the base of the dorsal root. The ventral root, which is without a ganglion, is made up

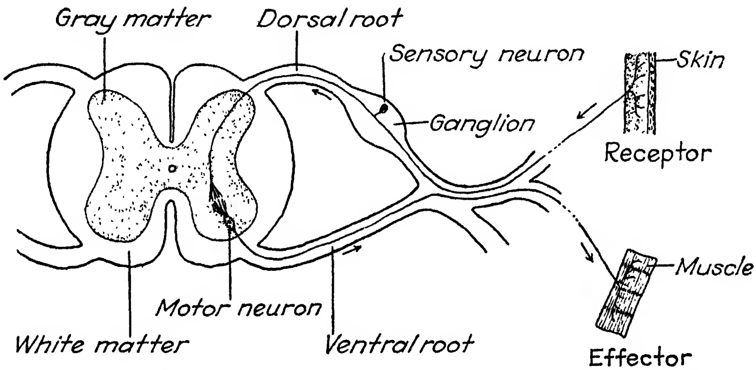


FIG. 151.—Diagrammatic cross section of the spinal cord with dorsal and ventral roots of a spinal nerve, showing neurons involved in a simple reflex arc. Arrows indicate path of a nervous impulse.

of the axons of motor neurons whose cell bodies and dendrites lie in the gray matter of the spinal cord. Some of the fibers of the dorsal root are directly in synaptic contact with the dendrites of the motor neurons in the spinal cord, while the connection of others is through one or more intermediate neurons. Each spinal nerve, after arising by its dorsal and ventral root, divides to form three branches, each of which contains both sensory and motor fibers. These branches go to different parts of the body.

In vertebrates, each neuron is connected with many other neurons, so that impulses may be transmitted along many paths. This makes possible different types of responses as well as the coordination of activities. Thus a stimulus causing a reflex action may reach the brain, and the response may be modified or supplemented by voluntary actions involving other parts of the body.

Sense Organs.—A *sense organ* is an organ specialized to receive a particular kind of stimulus, transform it into a nervous impulse, and transmit it to the brain. The organs of special sense are those concerned with sight, hearing, smell, taste, and touch.

Receptors sensitive to touch are distributed over the entire surface of the body but are especially numerous on the palms and fingers. The sense of taste is localized in groups of sensory cells forming *taste buds*. These are present in the mouth, particularly on the tongue, and are connected with branches of

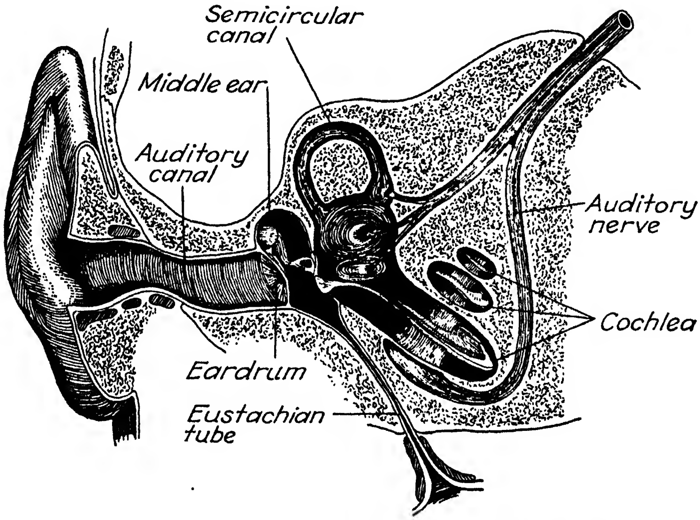


FIG. 152.—Diagram of the human ear. (*After Czermak.*)

the seventh and ninth pair of cranial nerves, by means of which taste sensations are transmitted to the brain. The taste buds can be stimulated only by substances in solution. Moreover, only four kinds of tastes can be distinguished—sweet, sour, bitter, and salty. Other apparent tastes are due to volatile substances that affect the nerves in the nose, and so are really odors. The sense of smell is localized in the mucous membrane of the nasal cavities. This contains sensory cells connected with nerve endings of the olfactory nerves, one of which leads from each nostril to the brain. Smell is a far more delicate sense than taste but is much better developed in such animals as the dog than it is in man.

The Ear.—The ear is an organ specialized for the reception of sound, the sense of hearing depending upon the transfer of impulses by the pair of auditory nerves from the ears to the brain. In man and other mammals the ear consists of three parts: the *outer ear*, the *middle ear*, and the *inner ear* (Fig. 152).

The outer ear leads to a canal, about 1 inch in length, the inner end of which is closed by the *eardrum*, or tympanic membrane. On the inner side of the eardrum is a small air-filled cavity, the middle ear. This is connected with the throat by the *Eustachian tube*, which serves to equalize the air pressure on either side of the eardrum. A chain of three small bones, called the *malleus*, *incus*, and *stapes*, extends across the middle ear, connecting the tympanic membrane with the inner ear. The inner ear, or *membranous labyrinth*, is a closed, fluid-filled sac. It comprises a vestibule into which open three *semicircular canals* and the spirally coiled *cochlea*. The semicircular canals are concerned not with hearing but with equilibrium.

Over the surface of the membrane that lines the cochlea are numerous sensory cells in contact with delicate terminal branches of the auditory nerve. The outer ear acts as a trumpet, collecting sound waves and directing them into the ear canal. These set up vibrations in the eardrum, which are then conducted by the three small bones of the middle ear to the liquid of the inner ear. The sensory cells in the lining of the cochlea transform the sound vibrations to nervous impulses that are transmitted to the brain by the auditory nerve.

The Eye.—The structure of the human eye is shown by Fig. 153. It lies in an *orbit*, or eye socket, and is protected externally by an upper and a lower *eyelid*. The eyeball is moved by six muscles, four of which are straight and two oblique. Its surface is kept moist and free from dust particles by a secretion from the *lachrymal gland*, from which numerous ducts lead to the inner surface of the upper eyelid.

The eyeball is nearly spherical. It has three coats: the *sclerotic coat*, the *choroid coat*, and the *retina*. The front of the eyeball is covered with the *conjunctiva*, a thin transparent membrane continuous with the mucous membrane that lines the inner surface of the eyelids. The sclerotic, or outer coat, is dense, opaque, and white. At the front of the eye it becomes the transparent *cornea*. Both the sclerotic coat and the cornea are

thick and tough. The choroid, or middle coat, contains numerous blood vessels. It separates from the sclerotic coat just back of the cornea and hangs down as a curtain, forming the *iris*. In the center of the iris is an opening called the *pupil*. Both the choroid coat and the iris are provided with a pigment that prevents light from entering except through the cornea. The expansion and contraction of the iris change the size of the pupil and regulate the amount of light passing through the lens.

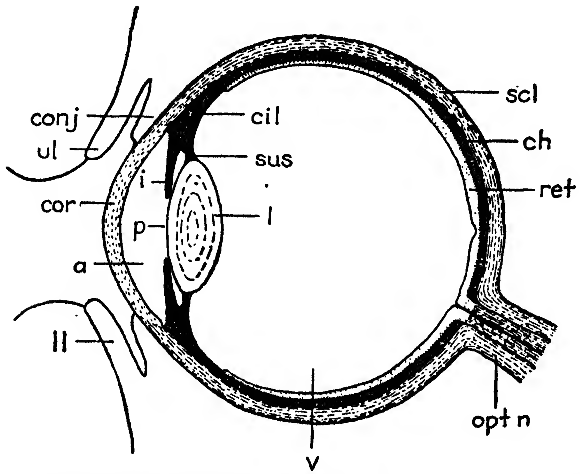


FIG. 153.—Diagrammatic longitudinal section of the human eye; *scl*, sclerotic coat; *ch*, choroid coat; *ret*, retina; *opt n*, optic nerve; *conj*, conjunctiva; *ul*, upper lid; *ll*, lower lid; *cor*, cornea; *a*, aqueous humor; *i*, iris; *p*, pupil; *cil*, ciliary muscle; *sus*, suspensory ligament; *l*, crystalline lens; *v*, vitreous humor.

The retina is the inner coat of the eyeball, forming a thin lining inside the choroid coat and extending forward almost to the iris. It is very complicated in structure, consisting of two kinds of neurons specialized for the reception of light. These are called *rods* and *cones*. Behind the iris is the *crystalline lens*, attached to the choroid coat by the *suspensory ligament*. The lens is biconvex and transparent. The space between the lens and the cornea is filled with a transparent liquid, the *aqueous humor*, while the much larger space behind the lens contains a transparent gelatinous substance, the *vitreous humor*. The cornea, aqueous humor, crystalline lens, and vitreous humor constitute a complex lens system that throws an image upon the retina. The focus of this lens system is controlled by the sus-

pensory ligament, attached to which are delicate *ciliary muscles*. These regulate the tension of the suspensory ligament, which in turn changes the thickness and curvature of the crystalline lens. When the lens is focused on nearby objects it is made more convex by contraction of the ciliary muscles; when focused on distant objects it is made less convex by relaxation of the ciliary muscles. The optic nerve connects the retina with the brain. It penetrates the sclerotic and choroid coats at the back of the eyeball. It is made up of the axons of sensory neurons, lying in the retina, which are connected by intermediate neurons with the light-sensitive rods and cones. Light stimuli, falling on the retina, produce nervous impulses that are transmitted by the optic nerve to the brain.

Chemical Coordination.—Although the coordination of bodily activities is brought about mainly through the agency of the nervous system, certain functions are controlled by special substances called *hormones*. These are secreted by glands but, unlike the products of other glands, are not carried by ducts but pass directly into the blood or lymph, this process being known as *internal secretion*. Some organs that produce hormones have other functions as well, examples being the pancreas and the sexual organs (testes and ovaries). The *endocrine*, or *ductless glands*, on the other hand, are special hormone-secreting organs. These include the thyroid, thymus, parathyroids, adrenals, and the pituitary body. In general, hormones regulate and coordinate certain functions, generally acting as either activating or inhibiting agents. Nearly always an abnormal condition arises from a deficient or an excess secretion of any hormone. For example, the development of a tadpole into a frog is determined by a hormone produced by the thyroid gland. If this gland is removed from a young tadpole, growth continues but metamorphosis fails to occur. On the other hand, a tadpole fed on thyroid extract undergoes a premature metamorphosis, developing into an undersized frog.

Thyroid Gland.—The thyroid gland is situated in the front of the neck. It consists of two lobes, one lying on either side of the trachea just below the larynx. This gland secretes *thyroxin*, a substance that has been found to contain about 65 per cent of iodine. Its chemical formula is $C_{15}H_{11}O_4NI_4$. Thyroxin controls the rate of oxidation in the body and so has a profound

influence on physical growth and mental development. A deficiency of thyroxin during childhood, usually arising from a degeneration of the gland itself, results in a form of dwarfness and idiocy known as *cretinism.* Degeneration of the thyroid during adult life produces a disease called *myxedema,* characterized by a low rate of metabolism, a peculiar thickening of the skin, and physical and mental sluggishness. The symptoms arising from underactivity of the thyroid, either during childhood or adult life, may be corrected by the feeding of thyroxin, artificially synthesized, or of thyroid extract, prepared from the thyroid glands of cattle or of other animals.

Goiter is an enlargement of the thyroid gland. *Simple goiter* is caused by a subnormal secretion of the thyroid hormone, this usually resulting, in turn, from an insufficient amount of iodine in the diet. It may be remedied or prevented, in most cases, by the eating of sea food or by the use of iodized table salt. *Exophthalmic goiter* is due to an excess secretion of thyroxin. This disease is characterized by a high rate of metabolism, nervousness, protruding eyeballs, etc. It may be relieved by surgical removal of a portion of the thyroid gland.

Thymus Gland.—The thymus, a small bilobed gland, lies in the upper part of the thoracic cavity below the thyroid. It is conspicuous in childhood but gradually becomes smaller during adolescence. Its functions are imperfectly known. The hormone secreted by the thymus gland has an effect upon growth and also seems to be responsible for the arrested development of the sexual organs during childhood.

Parathyroid Glands.—The parathyroids are four small glands attached to the dorsal surface of the thyroid, two on either side. They secrete a hormone that regulates the amount of calcium in the blood. An excess secretion results in an increase of calcium accompanied by softening of the bones and by muscular weakness. Removal of the parathyroids results in violent muscular contractions followed by death.

Adrenal Glands.—These two small bodies, one lying above each kidney, consists of a cortex, or outer covering, and a medulla, or central portion. The cortex secretes *cortin,* the medulla *adrenalin,* or *epinephrin.* A deficiency of cortin produces *Addison's disease,* an anemic, emaciated condition accompanied by a darkening of the skin, excessive weakness, etc. It is usually

fatal. Adrenalin is a powerful stimulant, an excess production of which, brought about by the emotional states of anger or fear, stimulates the heart and brain, causes contraction of the blood vessels, increases the concentration of sugar in the blood, and gives added strength to the muscles. Adrenalin can be prepared from the adrenal medulla in purified crystalline form and can also be made synthetically. Its chemical formula is $C_9H_{13}NO_3$. Adrenalin is used in medical practice to stimulate the heart, to raise the blood pressure, to arrest hemorrhage, etc.

Pituitary Gland.—This is a small, oval, bilobed body occurring at the base of the brain. The anterior lobe secretes several different hormones. One of these, called *tethelin*, regulates bodily growth, especially the size of the skeleton. An oversecretion of this hormone during youth gives rise to gigantism, while an undersecretion results in dwarfness. An oversecretion of tethelin during adult life produces *acromegaly*, a disease in which the bones of the face, hands, and feet enlarge abnormally. The posterior lobe of the pituitary body secretes *pituitrin*, a hormone that causes smooth (involuntary) muscle to contract. Its injection into the blood retards the pulse, raises the blood pressure, and causes contraction of the visceral muscles, particularly those of the intestine and uterus.

Other Glands.—Organs producing hormones, but which have other functions as well, include the sexual organs, the small intestine, and the pancreas. Hormones secreted into the blood by certain groups of cells in the testes and ovaries are responsible for many of the bodily changes that occur during adolescence. For example, a hormone produced by the testes brings about the development of the beard and deeper voice.

The production of bile and pancreatic fluid is brought about by a hormone called *secretin*. This is poured into the blood by the mucous membrane of the small intestine when the acidified chyme of the stomach comes in contact with it. The secretin, upon reaching the liver and pancreas, stimulates the flow of their fluids.

Insulin is a hormone secreted into the blood by certain groups of cells in the pancreas. It regulates the normal metabolism of carbohydrates. It does this by accelerating the rate of sugar oxidation in the tissues, by increasing the formation of glycogen in the liver, and by decreasing the amount of sugar produced from

fats and proteins. *Diabetes* is a disease resulting from an insufficient secretion of insulin by the pancreas. Its symptoms are mainly an increase in the amount of sugar in the blood and the presence of sugar in the urine. Diabetes may be controlled by a restricted use of carbohydrates in the diet and by the injection into the body of insulin prepared from the pancreatic glands of sheep or cattle. This treatment does not cure the disease but merely relieves the symptoms arising from it and permits the patient to lead a more healthy life.

CHAPTER XIV

REPRODUCTION AND DEVELOPMENT IN ANIMALS

The continuity of life is maintained by reproduction, the process by which an organism gives rise to others of its own kind. It is closely related to growth or development, which does not involve the production of a new individual, but merely an increase in size of one already in existence. In all multicellular organisms growth is accomplished by both cell division and cell enlargement, accompanied by more or less cell differentiation. In unicellular organisms, on the other hand, growth involves only cell enlargement, cell division resulting in reproduction. In animals, as in plants, reproduction may be either sexual or asexual, although the former is far more prevalent than the latter, except among the lowest groups. Sexual reproduction always involves a fusion of two gametes, while in asexual reproduction no such fusion occurs.

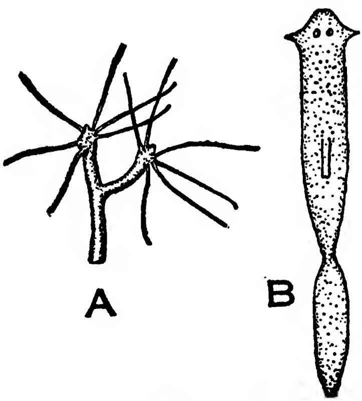


FIG. 154.—Fission in metazoans. *A*, in *Hydra; B*, in *Planaria*. (*From Wieman, "General Zoology." A, after Koelitz; B, after Child.*)

Asexual Reproduction.—We have seen that among the protozoans the prevailing method of reproduction is fission—an equal division of the body into two new parts that separate and take up an independent existence. Occasionally this happens among some of the lower metazoans, as in *Hydra* and the flatworm *Planaria* (Fig. 154). Spore reproduction, although characteristic of nearly all plants, is very rare among animals, occurring only in certain protozoans, such as the malarial parasite (see pp. 326–328). Other methods of asexual reproduction are found in animals, however, particularly among the lower groups of meta-

zoans. For example, attention has already been called to the formation of buds in *Hydra* (see p. 125), lateral outgrowths from the body wall that become detached and give rise to new individuals. This is a method of reproduction comparable to "vegetative propagation" among plants. Budding is common in the sponges, coelenterates, and flatworms, often giving rise to multicellular colonies, as previously explained. Among the higher animals, asexual reproduction is rare; in fact in the vertebrates it does not occur at all.

Sexual Reproduction.—Nearly all animals reproduce by the sexual method. In fact, in most cases, it is the only way by which new individuals arise, but even where asexual methods occur (as in *Hydra*), sexual reproduction is also present. Even many of the protozoans exhibit a form of sexual reproduction, although the rapid increase in number of individuals is brought about chiefly by fission. In *Paramecium*, for example, under certain conditions, a behavior known as *conjugation* takes place (Fig. 155). Two individuals come in contact with each other, complex nuclear transformations occur, and after an exchange of nuclear material, the two cells separate. Because no new individual is formed, strictly speaking, this behavior is not reproduction. The significance of conjugation has been variously interpreted but is still somewhat uncertain. It is only in a relatively few protozoans that gametes are formed and a permanent union takes place between them. In *Vorticella*, for example, one of the conjugating individuals is much smaller than the other, devoid of a stalk, and free swimming, an additional band of cilia occurring at the posterior end of the cell. A permanent union occurs between the conjugating individuals. In *Plasmodium*, the malarial parasite, eggs and sperms are differentiated (Fig. 227).

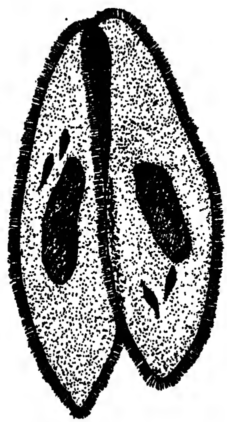


FIG. 155.—Conjugation in *Paramecium*.

Germ Cells.—In the growth of a metazoan from the fertilized egg, as we shall soon see, most of its cells become specialized to form muscle, nerve, blood, and other tissues that are primarily concerned with metabolic activities—with the maintenance of

the individual of which they are a part. These are called *somatic cells*, or, collectively, the *soma*, and are comparable to what are termed "vegetative tissues" in plants. Of all the cells that arise from the fertilized egg, however, a relatively few remain unspecialized, taking no part in general bodily functions. Except

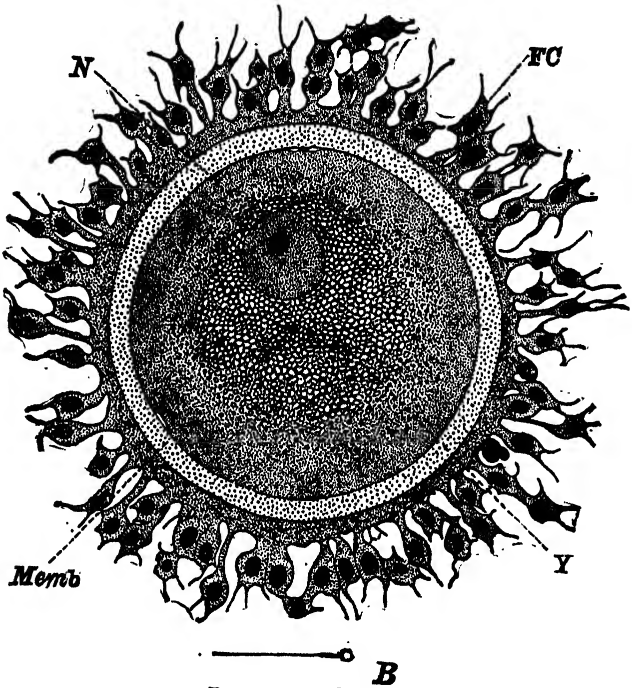


Fig. 156.—A nearly ripe human ovum in the living condition. The ovum is surrounded by follicle cells (*FC*) inside of which is the clear membrane (*Memb*) and within this is the ovum proper containing yolk granules (*Y*) and a nucleus (*N*) embedded in a clear mass of cytoplasm, × 250. *B*, two human spermatozoa drawn to about the same scale of magnification as the egg. (*From Conklin, "Heredity and Environment," Princeton University Press, after Hertwig; B, after Retzius; by permission.*)

in such simple metazoans as the hydra, these *germ cells*, as they are called, are set apart at a very early stage of embryonic development. As the body grows, they undergo a period of multiplication but are incapable of functioning as reproductive cells until the animal reaches maturity. Then they undergo certain complex changes (described in Chap. XV), and thereby become transformed into ripe gametes.

In the sponges, germ cells are scattered throughout the body, but in all other metazoans they are confined to definite sexual organs, *viz.*, *testes* and *ovaries*. These are temporary organs in the coelenterates, but permanent in all the higher groups. The male gametes of animals, called *sperms* or *spermatozoa*, are of various forms but are always very small and ordinarily consist of but little more than a nucleus (Fig. 156*B*). In most cases they swim by means of a flagellum or tail. The female gametes, called *eggs* or *ova*, are generally spherical in shape, are a great deal larger than the sperms but much less numerous, and are nearly always non-motile (Fig. 156). The human egg cell is approximately $\frac{1}{125}$ inch in diameter, while the sperm (including the tail) is slightly over $\frac{1}{500}$ inch long. Other eggs are much smaller than the human egg, and some a great deal larger. In addition to the nucleus, all eggs have a relatively large amount of cytoplasm containing reserve food, which constitutes the *yolk*. In some animals the yolk is uniformly distributed throughout the egg, while in others it accumulates at one end. In many cases part of the reserve food is stored in accessory layers, which surround the egg. Thus the white portion of a bird's "egg," called *albumen*, is merely accessory food material surrounding the yellow portion, the latter constituting the ovum or real egg enormously enlarged by the accumulation of yolk. The eggs of many animals are surrounded by a special protective envelope or *shell*, particularly in such forms as reptiles and birds, which lay their eggs on land. Its chief purpose is to prevent evaporation.

Fertilization.—Among animals, as among plants, the essential feature of sexual reproduction is the fusion of a male and female gamete, a new individual arising from the zygote by repeated cell division. All other features associated with reproduction are incidental; they merely aid in bringing about this gametic union or in providing a means for the new individual to develop. The sperm swims to the egg and penetrates its outer membrane. Its nucleus then gradually increases in size as it approaches the egg nucleus, and when the male and female nuclei fuse they may be approximately equal in size (Fig. 157). The egg is now said to be *fertilized*. Although an egg may be surrounded by millions of sperms, only one normally succeeds in effecting fertilization. It is important to realize that the fertilized egg or zygote gives

rise to all the cells of the adult individual. In fact, it is actually the new individual itself!

In order that the sperms may reach the eggs, there must be a liquid medium through which they can swim. In aquatic animals this is provided by the water in which they live. Most of the groups of invertebrates are aquatic, and consequently to them fertilization presents no difficulties. For example, in the starfish, where the sexes are separate, both the sperms and eggs are discharged into the water in large numbers, and there fertilization takes place. Among the vertebrates it is only in the fishes and amphibians that a similar condition exists. The eggs pass down through the oviducts and out of the body before being fertilized, and the sperms are discharged directly into the water, usually over the eggs just after they have been laid, as in most fishes, or while they are leaving the body, as in the frog.

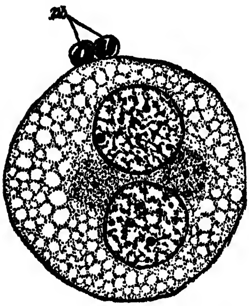


FIG. 157.—Fertilization in one of the roundworms (*Ascaris megalocephala*), the male and female nuclei in contact within the cytoplasm of the egg, × 1,000. *pb*, polar bodies.

In animals that do not live in the water, the means by which the gametes are brought together must necessarily be modified. Here the eggs are fertilized before they are laid. The sperms are introduced into the body of the female and swim to the eggs through fluids that are secreted for the purpose. Internal fertilization occurs in the insects and in a few other invertebrate groups, in a few fishes and amphibians, and in all reptiles, birds, and mammals. In some invertebrates the eggs are fertilized while still in the ovaries, but in the vertebrates fertilization occurs in the oviducts.

Parthenogenesis.—Although in the great majority of animals an egg will not develop unless a sperm has united with it, in some animals, mainly invertebrates, an unfertilized egg may give rise to a new individual directly. This phenomenon is known as *parthenogenesis*. It occurs, for example, in a group of microscopic aquatic forms called rotifers, in certain small crustaceans, and in such insects as plant lice or aphids, and among ants, bees, and wasps (Figs. 158 and 159). Sometimes no males are produced for many generations, and in some cases there are apparently no

males at all. In the bees and related insects the female lays both fertilized and unfertilized eggs, the former always develop-

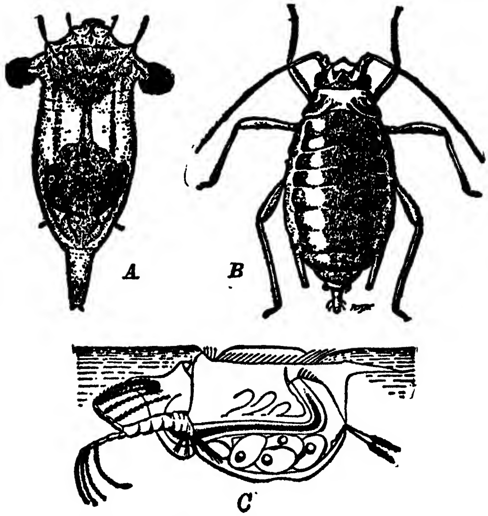


Fig. 158.—Parthenogenetic animals. *A*, a rotifer; *B*, an aphid; *C*, a crustacean. (*From Shull, "Heredity," A, after Harring; B, after Webster; C, after Storch.*)

ing into *queens* (fertile females) and *workers* (sterile females), the latter into *drones* (males).

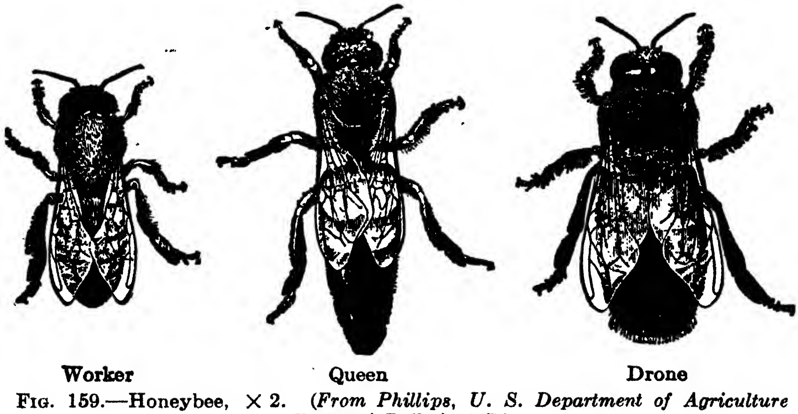


Fig. 159.—Honeybee, × 2. (*From Phillips, U. S. Department of Agriculture Farmers' Bulletin* 447.)

Early Embryonic Stages.—In the development of the embryo from the zygote, we find that the early stages are essentially similar in all metazoans, the differences that occur being mostly

in details. This development we shall follow in a very general way, using as an illustration the lancelet (*Amphioxus*), a very primitive chordate previously discussed on pp. 164 and 165.

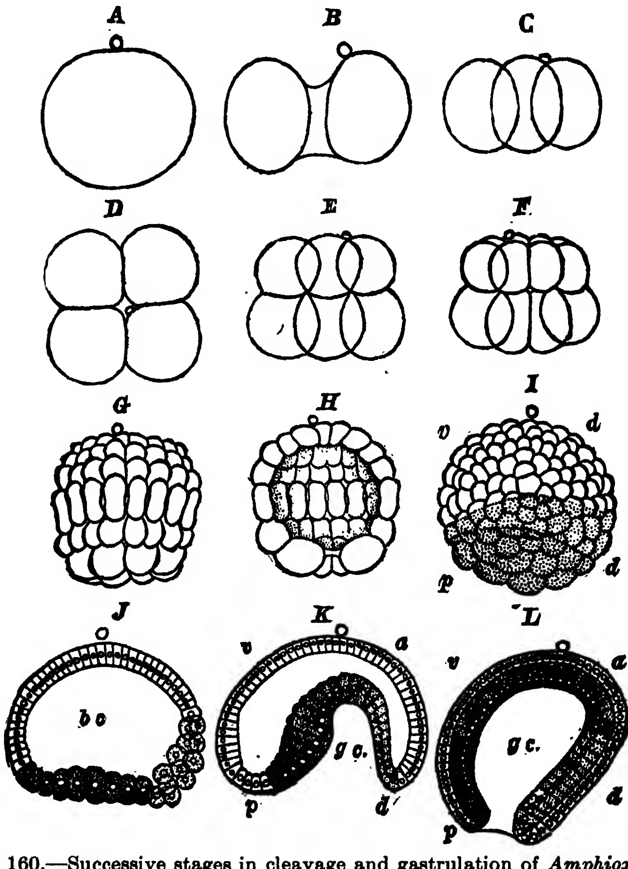


FIG. 160.—Successive stages in cleavage and gastrulation of *Amphioxus*. *A*, 1 cell; *B*, 2 cells; *C* and *D*, 4 cells; *E*, 8 cells; *F*, 16 cells; *G*, blastula stage of about 96 cells; *H*, section through same showing the cleavage cavity (blastocoele); *I*, blastula seen from the left side, showing three zones of cells, *viz.*, an upper clear zone of ectoderm, a middle (faintly shaded) zone of mesoderm, and a lower (deeply shaded) zone of endoderm cells; *J*, section through same showing these three types of cells; *K* and *L*, successive stages in the infolding of the endoderm. *a*, anterior; *p*, posterior; *v*, ventral; *d*, dorsal; *bc*, blastocoele; *gc*, gastrocoele. (*From Conklin, "Heredity and Environment," Princeton University Press, A–H, after Hatschek, by permission.*)

Shortly after fertilization has taken place, the zygote divides to form two cells that remain together (Fig. 160). Each of these then undergoes a division in a plane at right angles to the first

one, and four cells are formed. Then each cell divides in the third plane, resulting in the formation of eight cells. These early stages in the development of an individual are called *cleavage stages*. The process of cell division continues until a small spherical mass of cells is built up, and at the same time a central cavity, which is termed the *cleavage cavity* or *blastocoele*, appears. The embryo is now said to be in the *blastula* stage, a blastula being merely a hollow sphere consisting of a single layer of cells surrounding a cavity.

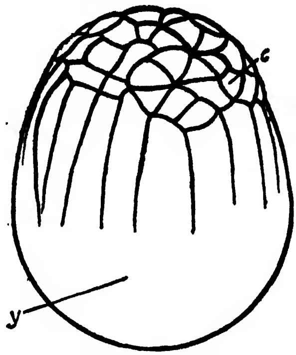


FIG. 161.—Cleavage in the egg of the gar pike (*Lepidosteus*), about 5 hours after fertilization. The yolk-laden half of the egg remains undivided. (*From Shull, "Principles of Animal Biology," after Eycleschymer.*)

The preceding account applies especially to the development of eggs in which the yolk is evenly distributed. In cases where a large amount of yolk is massed at one end of the egg, as in birds, reptiles, and most fishes, the cleavage divisions do not extend the entire length of the embryo, but the portion with the yolk remains undivided (Fig. 161). In the arthropods, where the yolk is confined to the center of the egg, cleavage involves only the peripheral portion (Fig. 170).

Gastrulation.—Following the formation of the blastula, a very important phase of development occurs (Fig. 160). The cells on one side of the embryo, which ordinarily are slightly larger than the others, begin to invaginate, or bulge inward, and this process continues until the lower and upper cells are in contact and the cleavage cavity is almost obliterated. The embryo is now called a *gastrula*. The new cavity formed by the process of gastrulation is known as the *archenteron* or *gastrocoele*, while the opening at one end of the embryo is the *blastopore*. The outer layer of cells comprises the *ectoderm*, the inner layer the *endoderm*.

As our study of the hydra has clearly shown, some animals go no farther in their development than the gastrula stage. Both the sponges[1] and coelenterates have only two layers of cells

[1] The outer and inner layers of a sponge seem not to correspond to the ectoderm and endoderm, respectively, of a coelenterate, since in the sponge's

surrounding a single cavity that communicates with the outside by means of one opening. Of course, many minor modifications in this fundamental plan arise, such as the development of tentacles in the hydra, but these are special features that are related to the life habits of the animal and enable it to carry on a

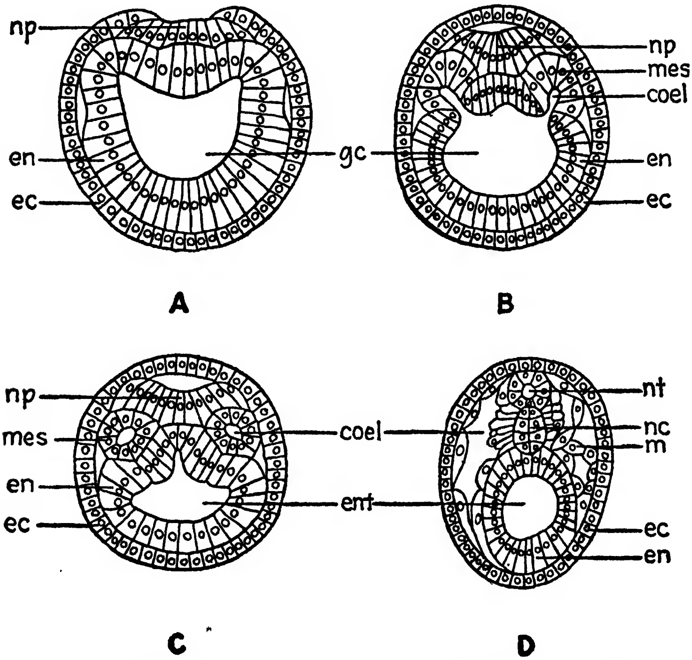


FIG. 162.—Cross sections of older embryos of *Amphioxus* in successive stages of development, showing the formation of coelom and mesoderm. *ec*, ectoderm; *en*, endoderm; *mes*, mesoderm; *np*, neural plate; *nt*, neural tube; *nc*, notochord; *gc*, gastrocoele; *coel*, coelom; *ent*, enteron. (*After Conklin, "Heredity and Environment," Princeton University Press, by permission.*)

separate existence. The most important fact to remember concerning the two lowest groups of metazoans is that they remain permanently in the gastrula stage of development.

In the higher animal groups, the gastrula now elongates somewhat, and further changes take place. The most important of these are concerned with the formation of the mesoderm and coelom.

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development the position of the primary layers apparently becomes reversed.

Mesoderm and Coelom Formation.—In all metazoans except the sponges and coelenterates, there now arises between the two primary layers of cells a third layer called the *mesoderm*, which may be derived from the ectoderm, endoderm, or both, depending upon the kind of animal (Fig. 162). The ectoderm, endoderm, and mesoderm constitute the three *primary germ layers*. From them are later derived all the specialized tissues of the body. As previously pointed out, animals without a mesoderm (sponges and coelenterates) are said to be *diploblastic*, while those with a mesoderm (all other metazoans) are *triploblastic*. This is an important distinction.

Another noteworthy feature of embryonic development is the differentiation of the archenteron into a *coelom* and an *enteron*, the former developing outside the latter (Fig. 162). As previously pointed out, a coelom is characteristic of all metazoans except the sponges, coelenterates, and flatworms. Thus the sponges and coelenterates have neither mesoderm nor coelom, the flatworms have mesoderm but no coelom, while the higher groups have both mesoderm and a coelom. The transitional position of the flatworms, from this standpoint, is very apparent.

The methods of mesoderm and coelom formation vary greatly among the different groups of metazoans, but these details are not important. A common method is shown in Fig. 162. Here the mesoderm is seen to arise from the endoderm by the formation of a pair of lateral pouches that become cut off, the archenteron thus giving rise to the coelom (surrounded by mesoderm) and the enteron (surrounded by endoderm). The embryo of the lancelet at this stage of development also shows the way in which the central nervous system of the chordates arises, *viz.*, as a dorsal infolding of the ectoderm, the edges of which unite to form a tube. The notochord is seen to arise as a dorsal outgrowth of the endoderm. This structure, it will be recalled, appears in the embryogeny of all chordates but is persistent throughout life only in the lower members of the phylum.

Later Development.—The further growth of the embryo is complex and subject to great variation among the higher metazoan groups. Up to this point there is little or no differentiation between the cells of the embryo, no specialized tissues being formed as yet. In the subsequent development, however, each of the three primary germ layers gives rise to definite sets

of tissues. In the vertebrates these are, in part, as follows: The ectoderm gives rise to the outer part of the skin, to certain superficial appendages, such as scales, hair, feathers, nails, etc., and to the entire nervous system. The endoderm forms the lining of the digestive and respiratory tracts and of the liver and pancreas. The mesoderm gives rise to the muscles, connective and supporting tissues, blood vessels, the blood itself, and most of the other tissues of the body. Nearly all the organs of the adult animal are composed of cells derived from more than one of the three primary germ layers of the embryo.

It is a remarkable fact that animals so diverse in their adult stages as an earthworm, a starfish, a frog, and a mammal should begin their development in essentially the same way and follow a similar sequence of stages. Minor variations are many, especially beyond the earliest stages, but the main features of development are constant. It is only in the later course of embryogeny —in the formation of organs—that a great deal of diversity arises.

Oviparity and Viviparity.—In animals with external fertilization, the embryo necessarily develops outside the body. Where fertilization is internal, however, the embryo may develop within the body, as in practically all mammals, or outside, as in all birds and most reptiles. In the two latter groups fertilization occurs before the shell is formed, and so when the "egg" is laid, the embryo has already started to develop inside it. The large amount of food present is entirely consumed by the embryo during the course of its development. Animals in which the embryo develops outside the body are said to be *oviparous*, regardless of whether fertilization is external or internal. Except in a very few cases, the invertebrates, fishes, amphibians, and reptiles are oviparous, while birds are oviparous without exception. Nearly all the mammals, on the other hand, are *viviparous*, which means that the embryo develops within the body, deriving its nourishment by direct absorption from the maternal tissues.

Only two egg-laying mammals are known: the duckbill or platypus (*Ornithorhynchus*) and the spiny anteater (*Echidna*), both natives of Australia and adjacent islands (Fig. 163). The young are hatched from a large shelled egg like that of reptiles and birds. These forms, known as *monotremes*, are the most

primitive mammals in existence. Not only are they oviparous, but they have a cloaca, an organ characteristic of lower vertebrates but absent in all other mammals. Another primitive feature of the monotremes is the fact that milk is secreted over the entire ventral surface of the body, the mammary glands not being localized to form *mammae* (nipples) as in other mammals.

Intermediate between the monotremes and the higher mammals are the *marsupials*, a curious group including the kangaroos

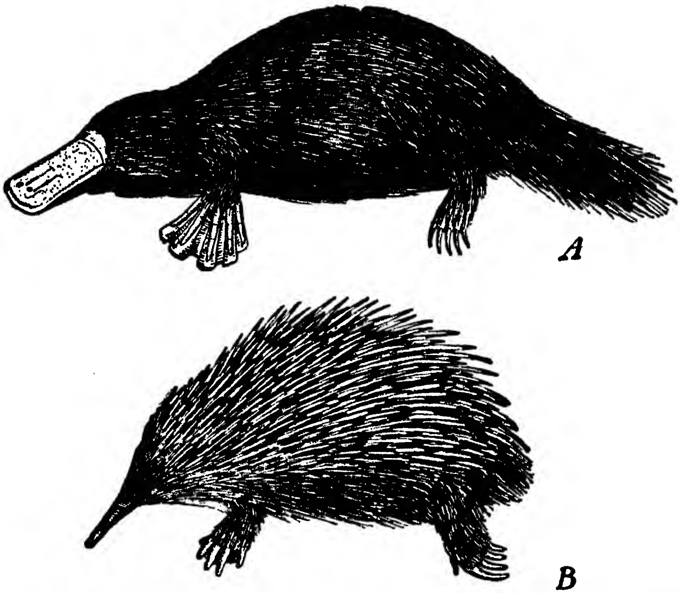


FIG. 163.—Egg-laying mammals. *A*, Duckbill (*Ornithorhynchus*); *B*, Spiny anteater (*Echidna*).

and their many Australian relatives, and the opossums of America. The eggs, which have no shells, develop within the mother's body, but there is only a slight connection between the embryo and the wall of the uterus, no true placenta being formed. The young are born in a very immature condition and are immediately placed in an abdominal pouch (*marsupium*) located on the ventral side of the female. Within this pouch are the mammae to which the young become fastened.

The following table is a convenient summary of the relations discussed above.

Group	Fertilization external or internal	Oviparous or viviparous
Invertebrates	Mostly external	Mostly oviparous
Fishes	Mostly external	Mostly oviparous
Amphibians	Mostly external	Mostly oviparous
Reptiles	Internal in all cases	Mostly oviparous
Birds	Internal in all cases	Oviparous in all cases
Mammals	Internal in all cases	Mostly viviparous

Intrauterine Development.—In all mammals except the monotremes and marsupials, the embryo, while within the body of the mother, receives its nourishment through an absorb-

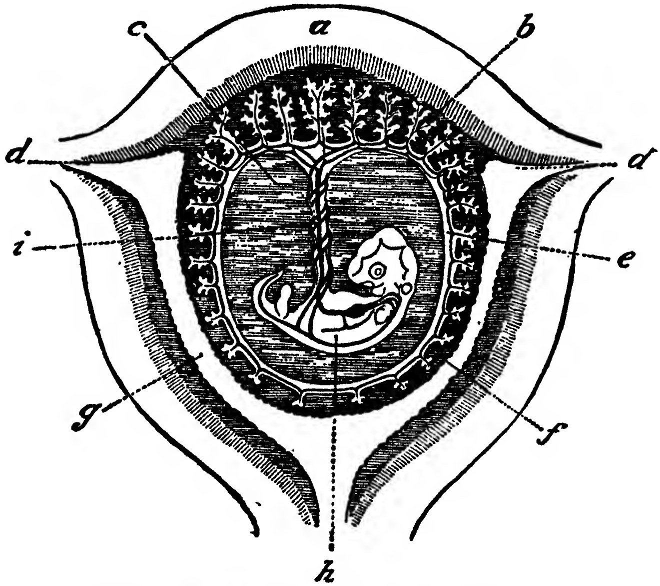


FIG. 164.—Diagrammatic section of human uterus with young embryo. *a*, dorsal wall of uterus; *b*, placenta; *c*, fluid-filled cavity surrounding embryo; *d*, lower ends of oviducts (Fallopian tubes); *e*, embryonic membranes; *f*, uterine tissue; *g*, uterine cavity; *h*, embryo; *i*, umbilical cord with blood vessels. (*From Woodruff, "Foundations of Biology," The Macmillan Company, by permission.*)

ing organ called the *placenta*, and thus nearly all mammals are *placental mammals* (see pp. 187–189). The general features of the female reproductive system of vertebrates have been illustrated by the frog, and it has been seen that the ripe eggs escape from the pair of ovaries, enter the open ends of the

oviducts, and pass downward to the uteri where they are temporarily stored (see p. 177). In mammals the uterus is similarly an enlargement of the oviduct. There may be either two separate uteri (as in most rodents), the uteri may be fused only at their lower ends (as in carnivores and many ungulates), or the fusion may be complete, resulting in a single undivided uterus (as in man and other primates).

Fertilization occurs in one of the oviducts, the zygote passing down into the uterus where the embryo undergoes its development. At first the embryo uses up the food previously stored in the egg, but soon another source of nourishment becomes necessary. This is obtained from the mother by means of an organic attachment between the embryo and the uterus (Fig. 164). A disk-shaped *placenta* is formed consisting of both maternal and embryonic tissues. It is firmly attached to the wall of the uterus and connected with the embryo by means of the *umbilical cord.* Food and oxygen are brought to the placenta by the maternal blood vessels and pass to the embryonic tissues by osmosis. The blood vessels of the embryo extend the length of the umbilical cord and into the placenta. They not only absorb nourishment and oxygen from the maternal circulation, but give back carbon dioxide and other waste products.

The foregoing facts make it clear that the embryo is essentially a parasite in the body of the mother. It should be distinctly understood, however, that the blood vessels of the mother and the embryo are entirely separate from each other, and consequently no blood passes between them. All the blood cells of the embryo, like all its other tissues, have been derived directly from the zygote. There is merely an osmotic movement through the placenta of food and oxygen from mother to embryo and of waste products in the opposite direction. There are also no nerve connections, and consequently there is no way in which the mental state of the mother—her thoughts, desires, or fears—can influence the unborn offspring.

Larval Stages.—Until the individual becomes independent of the mother or of the nourishment contained in the egg, it is an *embryo.* When it is born or hatched, as the case may be, it may be fairly well developed and thus show a general resemblance to the adult parents, or it may be very immature and very unlike the parents. For example, when a grasshopper's egg hatches,

the young individual is unmistakably a little grasshopper, but a butterfly's egg hatches into a worm-like caterpillar, an individual that bears practically no resemblance to the adult insect (Fig. 165). In all cases similar to the latter, the young is called a *larva.* Many other insects pass through a larval stage. In the

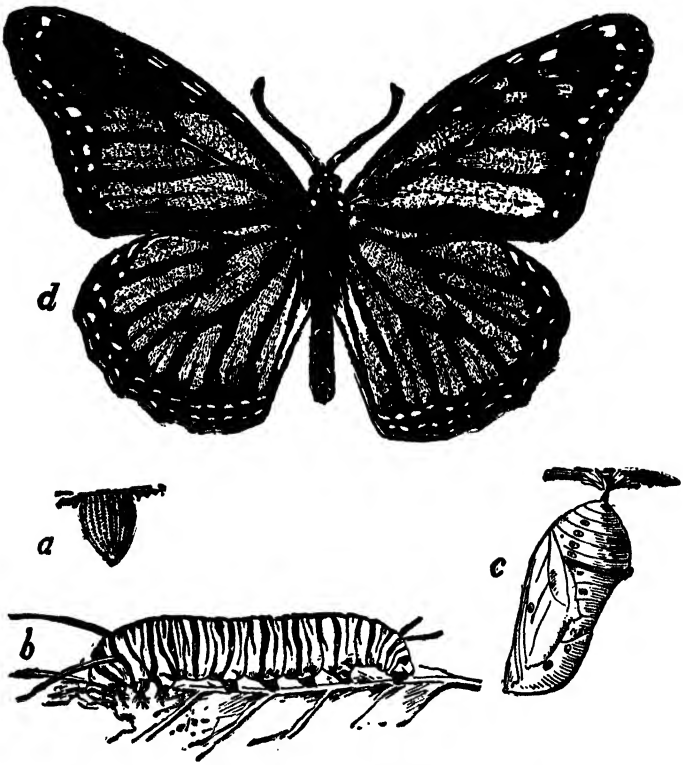


FIG. 165.—Metamorphosis of the monarch butterfly (*Anosia plexippus*). *a*, egg; *b*, larva; *c*, pupa; *d*, adult. (*From Jordan and Kellogg, "Evolution and Animal Life," D. Appleton-Century Company, Inc., New York, by permission.*)

butterflies and moths the young are called *caterpillars;* in the beetles, *grubs;* and in the flies, bees, wasps, and ants, *maggots.* These insects live for a relatively long time in the larval stage, and usually consume large quantities of food during this period. Then they go into a resting condition, called the *pupa* stage, in which further development takes place. Finally they emerge as full-fledged, active adults.

Among vertebrates it is only the amphibians that exhibit a larval stage in development. A tadpole is really a larva, leading an independent existence as it gradually develops toward the adult condition. Some of the salamanders do not go beyond the larval stage, but remain aquatic throughout life. The transformation of a larva into an adult is known as a *metamorphosis*.

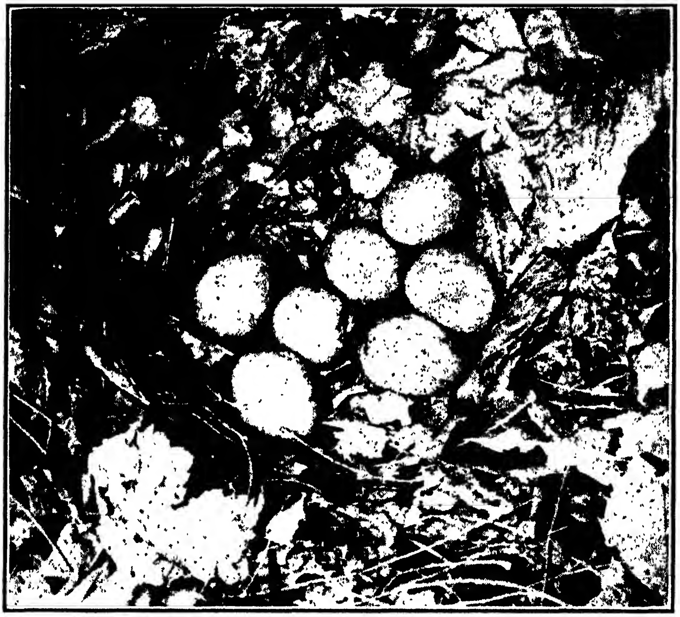


FIG. 166.—Nest of ruffed grouse.

Parental Care.—In most invertebrates and in nearly all vertebrates belonging to the three lower groups (fishes, amphibians, and reptiles) the eggs are laid without any further attention being given them by the parents. When the young are hatched they must shift for themselves. As might be expected, great numbers of eggs and young are eaten by other animals or destroyed by other deleterious agents. Consequently, in the lower groups, it is necessary that enormous numbers of eggs be produced, because few offspring reach maturity. In most of the birds and mammals, on the other hand, relatively few young are produced, but they are so protected that a much greater proportion survive.

In most birds the eggs are incubated by one or both of the parents, the heat of the body being essential to the growth of the embryo, and of course in the mammals the relation of the mother to the unborn young is much more intimate. The young of most birds and mammals are very helpless at birth, and cannot live without parental care. Thus in all our common songbirds the young are born blind, without feathers, and unable to walk or fly. They have to be raised in a nest of elaborate construction and be fed and protected by the parents. In such birds as gulls, snipe, ducks, grouse, quail, domestic fowls, etc., prenatal development goes much farther and when hatched the young are provided with a covering of down, have eyes, can walk, and need little or no parental care. Some of these birds make no pretense at nest building, merely depositing their eggs on the ground (Fig. 166). Others build a very crude nest that serves only to hold the eggs. A few birds do not even incubate their eggs, relying for heat upon some external source.

The young of mammals similarly exhibit various degrees of dependence upon the parents. For example, dogs, cats, and mice are born blind and in a very helpless condition, while newborn horses, cattle, and guinea pigs are much more mature and are soon independent of parental care. In all mammals the fact that the young are nourished by the mother's milk brings about a relation between parent and offspring that is absent in the lower groups. In fact, the long period of dependence of the human young upon the mother, both before and after birth, is regarded as having been a very potent factor in the evolution of the higher mental faculties and of social organization.

CHAPTER XV

PHYSICAL BASIS OF HEREDITY

All the characteristics of an organism, both structural and functional, arise from the interaction of two influences: *heredity* and *environment.* Their relation to each other, and the relative importance of each in the development of an individual, are problems of great interest, especially in their application to man. For the present we shall confine our attention to the great internal influence—heredity—reserving for subsequent chapters a consideration of the part that external factors play in determining the individual and racial constitution of organisms.

The fact that characters are transmitted through successive generations is self-evident. When a comparison is made between an individual and its parents, in a great many respects a marked similarity may be seen. This resemblance is not accidental, but due to the direct transmission from one generation to the next of a material substance—chromatin—possessing the possibilities for directing the development of the individual along certain definite lines. Thus the characters that an organism comes to have are largely predetermined by its ancestry, and the reappearance of parental characters in the progeny is due to an actual organic continuity between successive generations.

Although offspring tend to develop characters like those of their parents, a number of differences are always apparent. In general, "like begets like," but likeness is never complete. Every individual is unique, especially with respect to details. Fundamental similarity is the rule among organisms related by descent, but individual variability is apparent everywhere. Some of the differences between parents and their offspring are due to environmental influences, but usually most of them, like most of the resemblances, are due to heredity. Certain hereditary variations may represent new combinations of parental characters, while others may be due to the reappearance of ancestral characters latent in the parents. Thus an individual

may differ from both of its parents in a given particular, but resemble one or more of its grandparents or even a more remote ancestor. These facts make it clear that differences, as well as resemblances, may be inherited, and that a parent may transmit characters that he himself does not manifest, but, due to his inheritance, possesses in a latent condition.

The biological science of *genetics*, one of the most interesting fields of modern scientific study, deals with the resemblances and differences exhibited by organisms that are related by descent. It is concerned not only with the known facts and principles of heredity, but seeks to arrive at an ultimate understanding, so far as is possible, of all problems concerned with hereditary transmission. Like other fundamental scientific generalizations, the laws of heredity are essentially the same in all living things, and so what is learned from a study of one kind of organism may be applied to others.

Uniparental Inheritance.—Where reproduction is asexual, or where it is sexual but self-fertilization always occurs, it is evident that an individual has only one parent. In such cases there is practically complete resemblance between the parent and its offspring. For example, if a cutting taken from a grape vine is planted, it will produce exactly the same kind of grapes as if it had been left to grow as part of the original vine. Here the offspring is merely a detached portion of the parent, composed of precisely the same kind of protoplasm, and thus the complete hereditary resemblance between them is explained. The slight amount of variability that does occur among related individuals propagated asexually, or by repeated self-fertilization, arises for the most part under the influence of the environment. The foregoing facts make it clear that, where inheritance is uniparental, an individual transmits all its hereditary characters to all its offspring, and consequently the latter show not only almost perfect resemblance to the parent but also to one another.

Biparental Inheritance.—In all cases where sexual reproduction involving two different individuals occurs, a very different situation prevails from that which has just been described. Here every individual is strictly biparental in origin. It arises as a cell formed by the fusion of two gametes, each coming from a different parent. Even though the egg ordinarily is immensely larger than the sperm, both parents are equally potent in transmitting

hereditary characters.[1] In biparental inheritance an individual inherits some of its peculiarities from one parent and some from the other, but neither parent transmits all its hereditary characteristics to any one of its offspring. As a consequence, biparental inheritance results in a much greater degree of variability among offspring of the same parents than does uniparental inheritance, for each of the progeny may represent a different combination of ancestral characters.[2] This is particularly true if the parents belong to diverse racial stocks. It is evident that, from the standpoint of heredity, an individual must be regarded, not as a unit, but as an aggregation of innumerable characters, most of them independently heritable, which happened to have been brought together when the individual came into existence as a zygote, and which will later become separated and redistributed in various ways to its own offspring.

The Hereditary Bridge.—Since the only material contribution that each parent makes to its offspring is a gamete, it necessarily follows that this single cell carries the parent's entire hereditary contribution. This means that the zygote, formed through the act of fertilization, must contain all the potentialities for the complete development of the new individual. All the organism's inherent capacities are present in the zygote, having been brought together by the fusion of the two gametes. It is apparent, therefore, that because the gametes are the sole means of maintaining organic continuity between successive generations, they are the conveyors of the heritage.

It should be kept in mind that an organism's inheritance is the sum of its innate capacities. To say that characteristics or traits are inherited is to speak figuratively. It is obvious that a child cannot inherit any of its parents' actual peculiarities, as these belong to the parents. What it does inherit is something present in the gametes that *represents* characters and makes possible their subsequent development. It inherits potentialities—capacities for developing along some predetermined line.

[1] The reason for this is that the physical basis of heredity is contained in the nucleus, as will be seen later.

[2] The only exception occurs in the special case of identical twins; but here the two individuals are produced by fission from a single zygote, and so have the same inheritance. Thus their resemblance, amounting to practical identity, is explained (see also p. 260).

Vegetative or Somatic Mitosis.—The phenomena of hereditary transmission are closely associated with the process of cell division. When a cell gives rise to two new cells, they derive from it not only their living substance, but also their inheritance, which means their capacity to develop in a definite way. For this reason it is necessary to consider briefly, first the mechanism of cell division, and then certain matters closely associated with it.

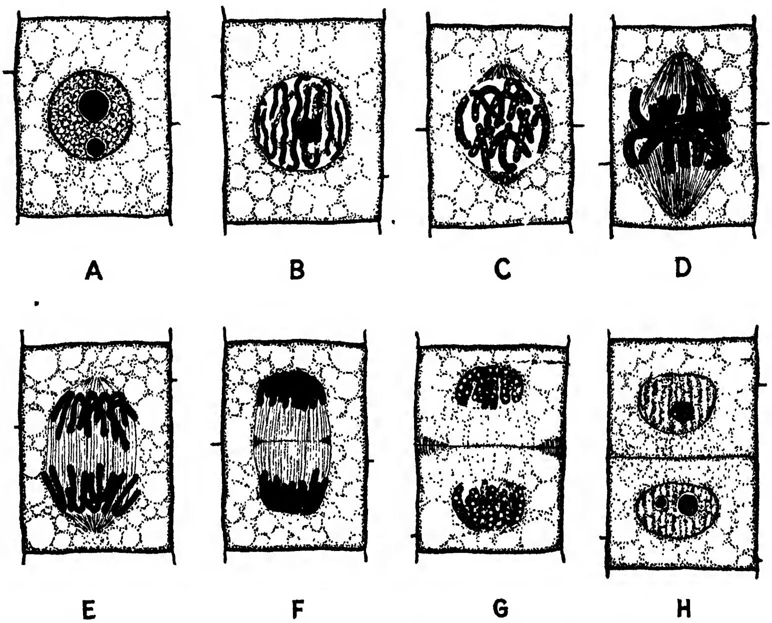


FIG. 167.—Successive stages in cell division in a root tip of onion (*Allium cepa*). *A*, resting cell; *B*, early prophase; *C*, late prophase; *D*, metaphase; *E*, anaphase; *F*, early telophase; *G*, late telophase; *H*, cell division completed.

In all multicellular organisms, growth takes place by the formation of new cells from those already present. In general, growth presents three overlapping phases, as follows: (1) A multiplication of cells occurs by *cell division;* (2) this is followed by a limited amount of *cell enlargement;* (3) finally, *cell differentiation* takes place, a particular kind of tissue being formed. We shall be concerned here only with the first phase of growth. Cell division in plants is confined largely to root tips, buds, and to the cambium of roots and stems. In animals it is most active in embryos but continues in all parts of the body until the adult stage is

reached. Then it is limited principally to groups of unspecialized cells, found in most tissues, which replenish wornout or injured cells.

Except in a few rare cases, cells divide by *mitosis*, a complex process in which the nucleus is conspicuously involved. It is essentially similar in both plants and animals. Figure 167, showing a series of stages in vegetative mitosis as seen in a root tip, should be carefully studied in connection with the following account.

When a cell is preparing to divide, the chromatin of its nucleus resolves itself, apparently by a process of condensation, into a definite number of rod-like structures called *chromosomes*. Two groups of delicate fibers now appear in the cytoplasm at opposite poles of the nucleus, each group radiating inward from its own common center. These constitute the *polar caps*. Meanwhile, the nuclear membrane and the nucleolus gradually disappear, and the fibers meet to form a bipolar *spindle*. At the equator of the spindle the chromosomes become arranged in a plane perpendicular to its long axis. By this time each chromosome has become longitudinally split into two equal parts. Some of the spindle fibers are attached to the chromosomes, while others extend from pole to pole. The halves of each split chromosome are now drawn to opposite poles of the spindle, apparently by a shortening of the spindle fibers that are attached to them. Upon reaching the poles, each group of chromosomes gradually becomes organized to form a new nucleus. At the same time, a new cell wall forms on the spindle midway between the two daughter nuclei, thus dividing the cell into two parts.

The initial stages of mitosis, up to the disappearance of the nuclear membrane, constitute the *prophase*. The stage during which the chromosomes lie at the equator of the spindle is called the *metaphase*, and that during which they move to the poles is the *anaphase*. After the chromosomes have arrived at the poles, the *telophase* is reached.

In animal cells, and in some of the lower plants, there are usually a pair of minute spherical bodies called *centrosomes* that are concerned with the formation of the spindle (Fig. 168). From these bodies fiber-like radiations extend in all directions, some of which form the bipolar spindle. Another conspicuous difference between most plant and animal cells is that in the latter

the cytoplasm divides by a simple constriction rather than by the formation of a cell wall.

Mitosis represents an elaborate mechanism that secures an exactly equal distribution of chromatin to each daughter nucleus and thus preserves a constant number of chromosomes throughout all the body cells of the organism. This is of the greatest significance in connection with hereditary behavior. With

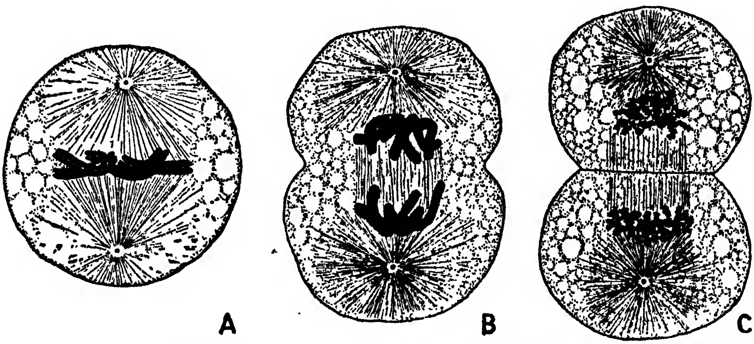


Fig. 168.—Fertilized egg of a roundworm (*Ascaris megalocephala*) showing three stages in cell division, × 1,000. *A*, metaphase; *B*, anaphase; *C*, telophase. The centrosomes with their conspicuous radiations are characteristic of animal cells.

few exceptions, the number of chromosomes is definite and constant for each species of plant and animal, as the following examples show:

Plants	Animals
Garden pea, 14	Hydra, 12
Onion, 16	Domestic fowl, 18
Indian corn, 20	Frog, 26
Lily, 24	Earthworm, 32
Tobacco, 48	Man, 48
Cotton, 56	Horse, 60
Shield fern, 144	Crayfish, 200

Significance of Fertilization.—When two gametes unite, the zygote receives two complete sets of chromosomes, one from the sperm and the other from the egg. Then when the zygote undergoes its first division, each chromosome splits longitudinally, as in an ordinary mitosis, the halves passing to opposite poles of the spindle. As a result, each of the daughter nuclei has a double set of chromosomes, half of which are paternal

in origin, half maternal (Fig. 169). Because this behavior is repeated with each subsequent somatic cell division, the double chromosome number is transmitted to all the cells of the embryo and eventually to all the somatic or vegetative cells of the adult organism. Thus each body cell contains a descendant of every chromosome that was present in the zygote; that is, it contains a definite number of *pairs* of chromosomes, one member of each pair being paternal in origin, the other maternal. For this reason, the members of each pair are said to be *homologous*. The

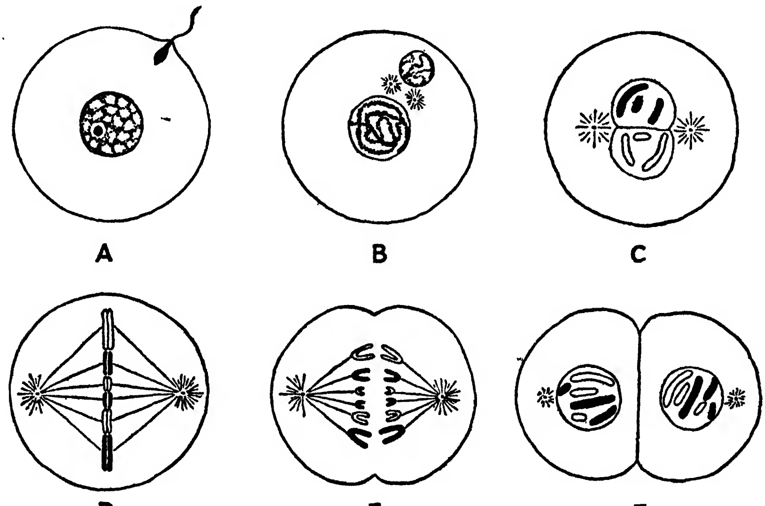


FIG. 169.—Diagram of fertilization and cleavage. Each of the two cells arising from the zygote has a double set of chromosomes, one set having been contributed by the sperm, the other by the egg.

two homologous chromosomes forming each pair are alike in size and shape (except in the case of the XY pair described on p. 258), and each pair may have its own structural individuality, often differing conspicuously from other pairs. The body cells, having a double set of chromosomes, are designated as *diploid*, the gametes, with a single set, as *haploid*. It is important to understand how this reduction in chromosome number is brought about.

Reduction of Chromosomes.—It has already been stated that sperms and eggs in animals are derived from unspecialized cells

called *germ cells,* and not from differentiated somatic tissues (see pp. 229–231). In some cases it is possible to identify in a very early stage of embryonic development a *primordial germ cell* from which all the germ cells will be derived (Fig. 170). All the other cells of the embryo become specialized to form somatic tissues and take no part in reproduction. As development proceeds, the germ cells undergo a period of multiplication, dividing by the regular mitotic process to form a large number of *spermatogonia* in the male and *oögonia* in the female. Some of these now increase in size, becoming *primary spermatocytes* and *primary oöcytes,* respectively. The primary oöcytes are much less numerous than the primary spermatocytes but become a great deal larger. When the animal has reached maturity, some of the germ cells ripen, and this ripening process, called *maturation,* in most cases continues throughout the lifetime of the individual.[1]

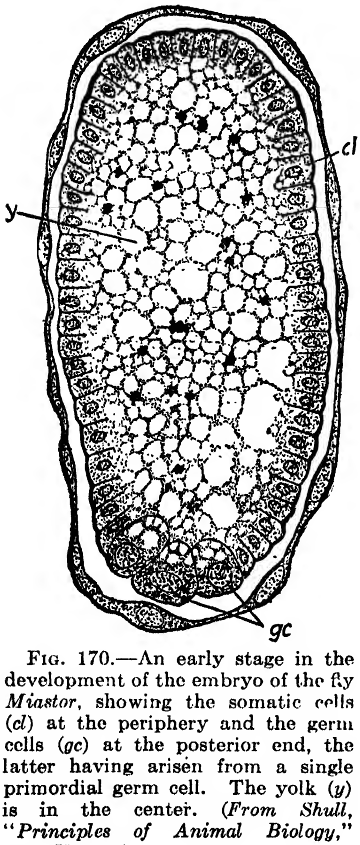


FIG. 170.—An early stage in the development of the embryo of the fly *Miastor*, showing the somatic cells (*cl*) at the periphery and the germ cells (*gc*) at the posterior end, the latter having arisen from a single primordial germ cell. The yolk (*y*) is in the center. (*From Shull, "Principles of Animal Biology," after Hegner.*)

Reduction in the number of chromosomes takes place in animals directly in connection with the formation of gametes (Fig. 171). Maturation of the germ cells involves two cell divisions; that is, each unripe

[1] In the human male, the germ cells continue to multiply during childhood, but in the female the period of multiplication ends before birth. During childhood the female germ cells increase in size and accumulate reserve food, but otherwise remain dormant. The liberation of ripe eggs from the ovaries, called *ovulation*, normally takes place only between the ages of thirteen and forty-five, and it is supposed that one or two eggs are extruded every 28 days. It is at the time of ovulation that the germ cells undergo maturation.

germ cell produces four potential gametes. Like all the somatic cells, the unripe germ cells are diploid. At the time of the first cell division, the chromosomes, after being formed from the chromatin of the resting nucleus, come together in pairs

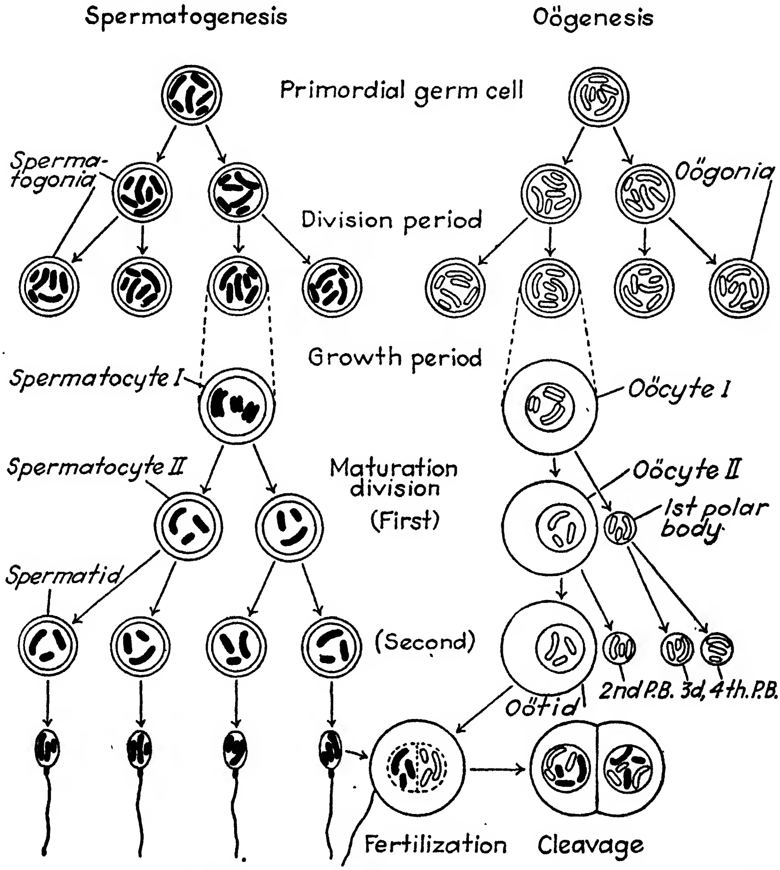


FIG. 171.—Diagram showing the behavior of the chromosomes in the multiplication and maturation of the germ cells, in fertilization, and in cleavage. During the multiplication period, the primordial germ cells, by an indefinite number of cell divisions (only two of which are shown in the diagram), give rise to a large number of unripe germ cells (called *spermatogonia* in the male and *oögonia* in the female), all of which are diploid.

and remain in contact until the bipolar spindle is formed. This unique pairing of the chromosomes, which takes place at no other time in the life history, is called *synapsis*. It is apparent that there are half as many chromosome pairs as there

were separate chromosomes in the unripe germ cell. Each chromosome of every pair now splits longitudinally, but unlike what takes place in an ordinary mitosis, there is no immediate separation of the halves. Instead, the two split chromosomes constituting every pair merely separate and move to opposite poles of the spindle (Fig. 172). Upon completion of the mitosis, each of the two daughter nuclei contains one member of every pair of chromosomes present in the nucleus from which they

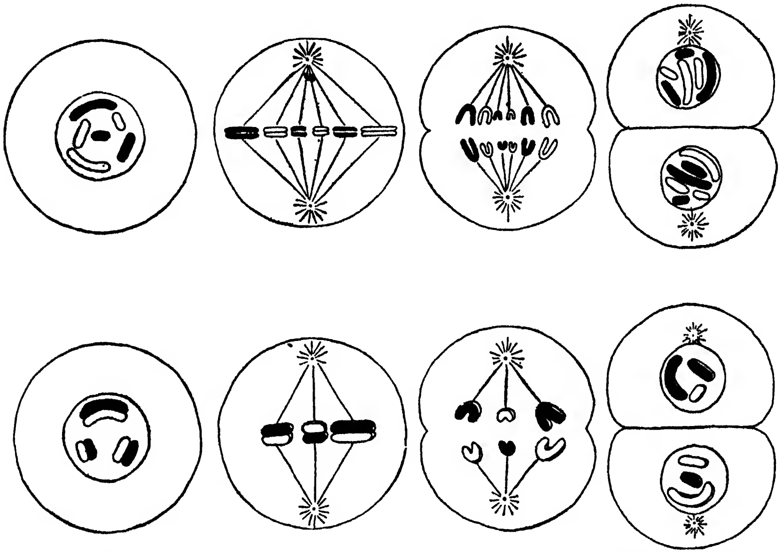


FIG. 172.—Diagram showing the difference between the behavior of the chromosomes during a somatic cell division (upper line) and a reduction division (lower line).

have been derived, but every chromosome is longitudinally split in preparation for the next mitosis.

The second division follows at once, often before the two daughter nuclei have returned to the resting condition. When a spindle is organized in each nucleus, the two halves of every split chromosome simply pass to opposite poles, so that the four resulting nuclei have half as many chromosomes as were present in the unripe germ cell. It should be borne in mind that each of the four haploid cells that come from an unripe germ cell contains descendants of only one member of each pair of chromosomes that were present in the unripe germ cell.

Although the essential features of maturation, as outlined above, are the same in both sexes, a slight difference occurs. In the male, each primary spermatocyte gives rise to two *secondary spermatocytes*, each of which, in turn, divides to form two *spermatids*. These are transformed directly into sperms. Thus each of the four cells derived from a primary spermatocyte becomes a functional sperm. In the female, however, the division of the primary oöcyte results in two cells that are very unequal in size, the larger one being the *secondary oöcyte* and the smaller one the *first polar body* (Fig. 171). The latter may or may not divide again, but the secondary oöcyte always undergoes another unequal division, producing the *second polar body* and the *oötid*, or mature egg. Thus each primary oöcyte gives rise to a single large egg and two or three small polar bodies. The egg alone is functional, the polar bodies soon disintegrating. In this way one cell gets all the yolk that otherwise would be equally divided among four cells.

Grouping of Chromosomes in Gametes.—Two very important details concerning the process of reduction remain to be considered. (1) At synapsis the pairing of chromosomes is not promiscuous but always involves homologous chromosomes. Each pair consists of a descendant of a chromosome originally contributed by the sperm, during the previous act of fertilization, and a descendant of a chromosome corresponding to it in size, form, and other respects originally contributed by the egg. (2) When the separation of these homologous chromosomes takes place during the reduction division, it is entirely a matter of chance to which pole either member of a pair passes, since this depends upon the position in which each chromosome happens to lie, with reference to its mate, when they are lined up on the equator of the spindle preparatory to separation. Consequently each of the two resulting cells has a different assortment of paternal and maternal chromosomes, but only one member of each pair of homologous chromosomes can be present. Then, when four cells are produced by the regular mitotic division that always follows the reduction division, each pair of cells has a different assortment of chromosomes.

To illustrate, in an animal where the diploid number of chromosomes is six, the paternal chromosomes may be designated as *A*, *B*, and *C*, the maternal ones as *a*, *b*, and *c* (Fig. 173). All

the somatic cells and unripe germ cells contain three kinds of chromosomes and two chromosomes of each kind, one paternal and the other maternal. In synapsis, *A* pairs with *a*, *B* with *b*, and *C* with *c*. Since the gametes can have only one member of each pair of homologous chromosomes, it follows that there can be eight possible kinds of gametes formed in approximately equal numbers. In other words, there are eight different ways in which the three kinds of chromosomes may be grouped: *ABC*, *ABc*, *AbC*, *Abc*, *aBC*, *aBc*, *abC*, and *abc*.

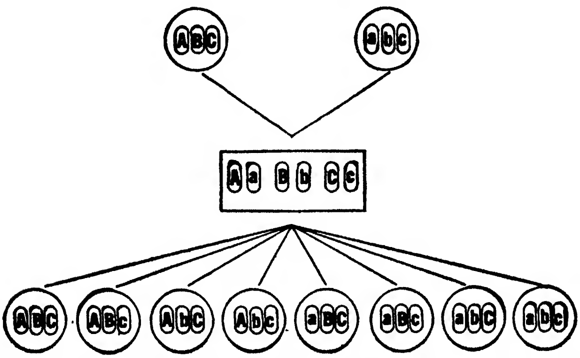


FIG. 173.—Diagram illustrating the distribution of paternal and maternal chromosomes to the gametes formed by the offspring. The number of different kinds of gametes depends upon the number of chromosomes.

That the number of possible kinds of gametes formed depends on the number of chromosomes is shown as follows:

Pairs of chromosomes in unripe germ cells	2	3	4	5	6
Number of possible kinds of gametes	4	8	16	32	64, etc.

In the case of man, where the number of chromosome pairs is 24, the possible number of different kinds of gametes is 16,777,-216. It is evident that this fact accounts for the diversity that prevails among offspring of the same parents.

Because the number of chromosomes is doubled in fertilization, a reduction must occur before or when gametes are formed in order that the number of chromosomes can remain constant through successive generations of diploid individuals. Assuming that the chromosomes are the bearers of hereditary elements, the association of paternal and maternal chromosomes in fertilization and their subsequent separation at the time of reduction according to the law of chance, explain four things: (1) why

inheritance in all organisms that reproduce by sex is biparental (except in cases of self-fertilization and parthenogenesis); (2) why the male and female are equally potent in transmitting their hereditary characters; (3) why the same combination of paternal and maternal chromosomes do not enter into the formation of every gamete that an individual produces; (4) why fertilization effects innumerable new combinations of ancestral characters.

Significance of Alternating Generations.—Alternation of generations in plants involves more than the production of two kinds of

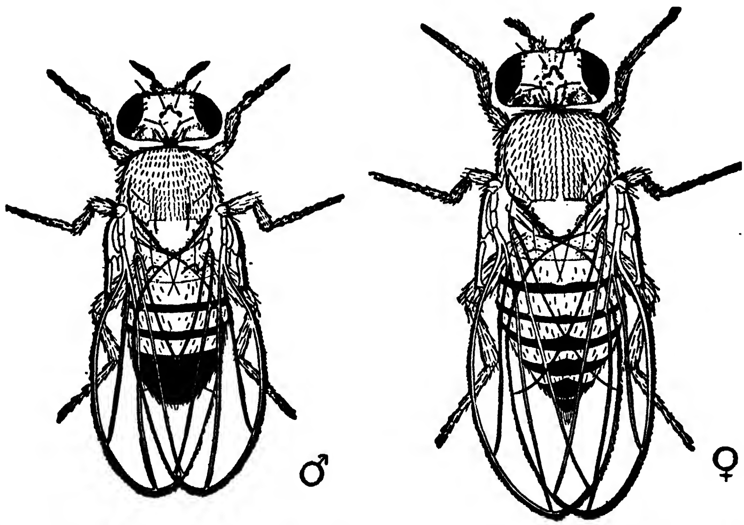


FIG. 174.—Male and female fruit flies (*Drosophila melanogaster*). (*From Morgan, "Physical Basis of Heredity," J. B. Lippincott Company, by permission.*)

plant bodies in the life history (see pp. 49–51). It introduces definite haploid and diploid individuals, the gametophyte representing the former and the sporophyte the latter. The zygote, formed by the fusion of two gametes, is the first cell to have the diploid number of chromosomes. This number is then transmitted to all the cells of the sporophyte. When spores are formed, however, the reduction of chromosomes takes place, so that each spore is haploid. When the spore germinates, the haploid number is carried over to all the cells of the gametophyte, including the gametes. In animals, reduction of chromosomes always occurs directly in connection with the formation of gametes, but in some of the thallophytes and in all the three

higher plant groups it takes place when spores are produced, the spores being formed in groups of four.

Determination of Sex.—In the fruit fly (*Drosophila melanogaster*), an insect that has been extensively studied by geneticists, each of the body cells has eight chromosomes (Figs. 174

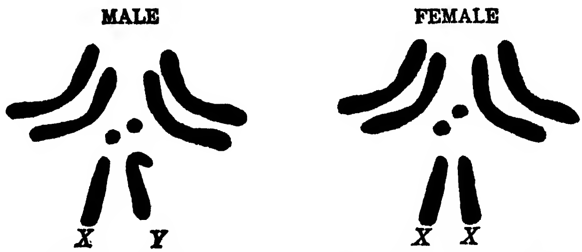


Fig. 175.—Diagram showing the chromosomes that occur in all the somatic cells of the fruit fly (*Drosophila melanogaster*). In the male an *X*- and a *Y*-chromosome correspond to the pair of *X*-chromosomes of the female. (*After Morgan.*)

and 175). There are two pairs of large curved chromosomes, one pair of very small ones, and one pair of straight chromosomes about two-thirds as long as the curved ones. A slight visible difference exists between the sexes in that, in the male, the end

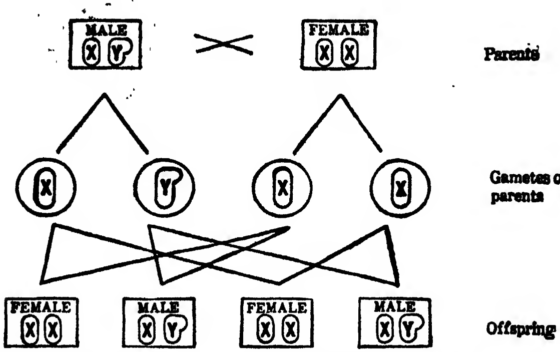


Fig. 176.—Diagram showing the mechanism of sex determination in the fruit fly. The sperms are of two kinds, the eggs all alike. The sex of any one of the offspring depends upon the kind of sperm that entered into the formation of the zygote from which it has developed.

of one of the straight chromosomes is slightly hooked. This is known as the *Y*-chromosome, while the straight ones, of which the male has one and the female two, are called *X*-chromosomes.

Since all the body cells and unripe germ cells of the female have a pair of *X*-chromosomes, it follows that, in the formation

of gametes, each egg will contain a single X-chromosome. The male, on the other hand, will form two kinds of sperms: half of them will have an X-chromosome and half a Y-chromosome. If an egg is fertilized by a sperm of the first type, the result is an XX-zygote; if fertilized by the other kind of sperm, an XY-zygote is formed (Fig. 176). The former develops into a female, the latter into a male. Because the two kinds of sperms are equally numerous, random mating of gametes will produce as many XX- as XY-zygotes, and thus the number of male and female offspring will tend to be equally numerous.

There are a great many other kinds of animals in which a Y-chromosome has been identified in the male. In some cases it differs from its mate in size rather than shape, or there may not be any apparent difference at all. Occasionally the Y-chromosome is absent, the X-chromosome in the body cells of the male then being unpaired. For example, in the squash bug (*Anasa tristis*), the female has 22 chromosomes and the male only 21, the missing one being the Y-chromosome. Consequently all the eggs and half of the sperms have 11 (10 plus an X-chromosome), the rest of the sperms having only 10. For this reason, and for others, it seems probable that it is not the presence of the Y-chromosome in the zygote that causes it to develop into a male individual but the presence of only a single X-chromosome.

In the case of man there has been a diversity of opinion in regard to the total number of chromosomes and to the difference between the male and female sets. It now seems certain, however, as a result of very careful recent investigations, that both sexes have 48 as the diploid number, but in the male the Y-chromosome is very small.

Although most cases of sex determination follow the same scheme as that described above, in a few animals the situation is slightly different. For example, in birds and in moths it has been found that the female produces two kinds of gametes, those of the male being all alike. So here sex is determined by the chromosome equipment of the egg, but the mechanism is exactly the same as where the male produces two kinds of gametes.

In only a few plants where male and female individuals are differentiated has a visible chromosome difference been discovered. There is reason to believe, however, that future research will show that the causes underlying sex determination in plants and animals are practically the same.

That the sex of an individual is determined at the time of fertilization is substantiated by the fact that identical twins are always of the same sex. Human twins are of two sorts: those coming from two different zygotes (*fraternal twins*), and those which arise from the splitting of an embryo in an early stage of cleavage (*identical twins*). The former may or may not be of the same sex, and are no more alike in their hereditary characters than ordinary brothers and sisters born at different times. The latter, however, are invariably of the same sex and are alike in regard to all their other hereditary characters. This is because they have exactly the same chromosome equipment, both individuals having arisen from the same zygote.

CHAPTER XVI

MENDELIAN LAWS OF HEREDITY

The foundation for our present knowledge of heredity was laid by the work of Gregor Mendel, an Austrian monk (Fig. 177). He crossed certain varieties of garden peas and discovered that their differentiating characters are inherited in accordance with definite mathematical laws. Mendel published his results in

Fig. 177.—Gregor Mendel, 1822–1884.

1866, but unfortunately his paper attracted little attention and remained unnoticed until 1900, when it was brought to light and its great significance appreciated. Biologists have since found that the laws of heredity discovered by Mendel apply to all organisms, including man, and thus are of fundamental importance.

Two plants are crossed by taking pollen from one and applying it to the pistils of the other. In most cases, the unripe stamens

of the second flower must first be removed so that self-pollination cannot occur. The seeds produced as a result of a cross, when planted, give rise to hybrids. A *hybrid* is simply an organism whose parents represent two distinctly different types of individuals. They may belong to the same species or to different species, but ordinarily individuals that are not rather closely related cannot be crossed; that is, no offspring will result. As an illustration of Mendel's first law, for the sake of simplicity, we

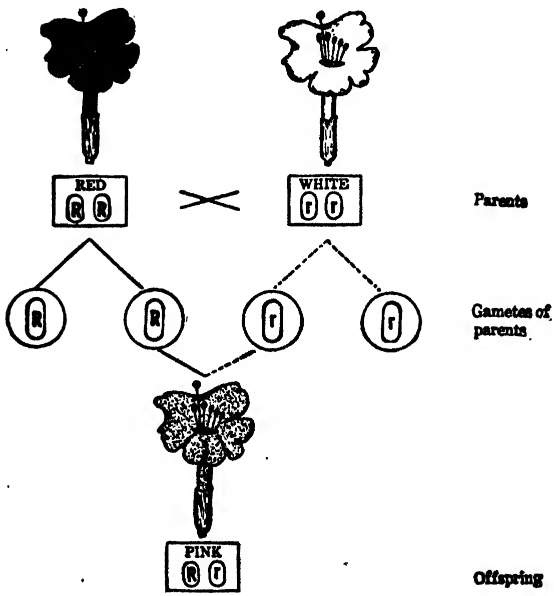


FIG. 178.—Diagram of a cross between a red-flowered and a white-flowered four o'clock (*Mirabilis*), showing the history of the chromosomes carrying the genes for red (*R*) and for white (*r*) flower color. The hybrids are intermediate between the parents.

shall choose a different kind of plant from the one with which he experimented.

Principle of Segregation.—A four o'clock (*Mirabilis jalapa*) having red flowers is crossed with a white-flowered plant. When the seeds are planted they give rise to hybrids with pink flowers (Fig. 178). If the reciprocal cross is made, that is, white with red (pollen being taken from the former instead of the latter), the result is exactly the same. In either case, the hybrid plants are intermediate between the parents. When these hybrids are allowed to pollinate themselves, however, the resulting seeds

give rise to three kinds of individuals in the ratio of 1:2:1. In other words, approximately 25 per cent of the plants will have red flowers, 50 per cent pink, and 25 per cent white (Fig. 179).

The red-flowered plants derived from the pink parents "breed true," which means that when self-pollinated they produce only plants with red flowers. Similarly the white-flowered plants give rise to only white-flowered progeny. The pink-flowered individ-

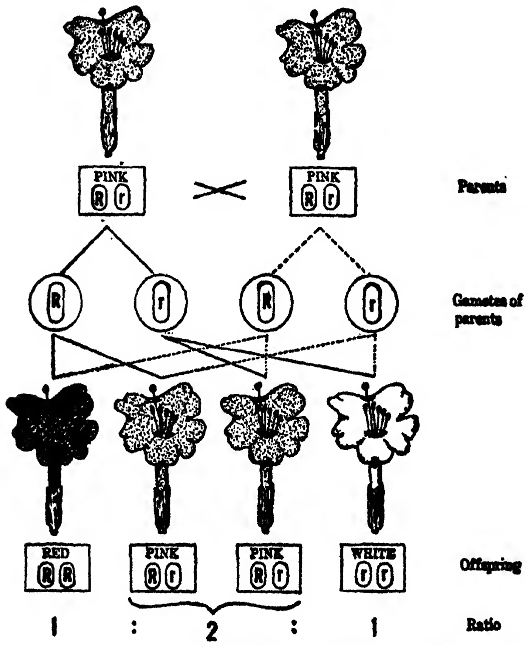


FIG. 179.—The principle of segregation. Diagram illustrating the results of interbreeding pink-flowered four o'clocks. The 1:2:1 ratio arises from the fact that each of the hybrid parents produces two kinds of gametes.

uals, however, always produce offspring in the ratio of 1 red:2 pink:1 white. It is therefore apparent that pink-flowered four o'clocks are always hybrids, and 50 per cent of their offspring are likewise hybrids.

A similar case among animals is seen in Andalusian poultry. There are three kinds of Andalusian fowls: black, white, and speckled (called "blue"). Blacks crossed with whites, or *vice versa*, always give rise to blue offspring, but when blue fowls

are interbred, the result is 1 black: 2 blue: 1 white, on the average. Blue Andalusians are hybrids exactly comparable in their behavior to pink-flowered four o'clocks.

Hereditary Elements.—The explanation of Mendel's principle of segregation is seen in the behavior of the chromosomes during fertilization and reduction (Fig. 178). Hereditary characters are represented in all the cells of an organism by invisible units or elements called *genes*, which are associated with the chromosomes. In the four o'clock the gametes have eight chromosomes, the haploid number. All the gametes produced by a red four o'clock carry on one of their chromosomes a gene for red flower color. This may be designated as *R*. When an egg and a sperm unite, each carrying an *R* gene, the zygote receives two *R* genes and all the vegetative cells derived from it the same. Hence the plant, designated *RR*, will have red flowers. Similarly all the gametes of the white four o'clock have a gene for white flower color (or lack the red gene, which amounts to the same thing), and so the plant is designated by the formula *rr*.

When a red four o'clock is crossed with a white one, the zygote receives from one gamete a chromosome bearing an *R* gene, from the other a homologous chromosome having an *r* gene (Fig. 178). Thus the pink hybrid is designated *Rr* because all its vegetative cells contain one gene for red (*R*) and one for white (*r*) flower color. Because homologous chromosomes always separate when the reduction division occurs, the members of the pair of alternative genes must also separate and go to different cells. As a result, there are two different kinds of gametes (both eggs and sperms) formed by the hybrid in approximately equal numbers: half of them have only the *R* gene, half only the *r*. In other words, since a gamete can have only one member of each pair of homologous chromosomes, it can carry a gene for only one member of each pair of genes.

In regard to any given character, if both members of a pair of genes are the same, as in the red (*RR*) and white (*rr*) four o'clocks, the individual is said to be *homozygous* for the character in question. But if the two genes in each body cell are different, that is, if they are contrasted or alternative in their relation to each other, as in the pink (*Rr*) four o'clock, the individual is termed *heterozygous*.

The essential feature of Mendel's principle of segregation may be stated as follows: The genes representing each member of a pair of contrasted characters, when brought together by two gametes uniting in fertilization, coexist in all the cells of the offspring and later become separated in their own gametes without having had any effect on each other.

Gene Combinations.—Pink-flowered four o'clocks produce two kinds of sperms and two kinds of eggs, as has been stated. When two pink plants are crossed, or when self-pollination occurs, the gametes pair according to the law of chance. In other words, there is a random mating of two kinds of sperms (R and r) with two kinds of eggs (R and r) (Fig. 179). This results in four possible combinations (R with R, R with r, r with R, and r with r), which occur in the same frequency; one is likely to occur as often as any other. Of these four possible gametic unions, two (R with r and r with R) give rise to the same kind of zygote (Rr), and thus the 1:2:1 ratio is explained. A careful study of Fig. 179 should make these points clear.

The situation just described is comparable to the simultaneous tossing of two coins. Referring to the two sides of the coin as head (H) and tail (h), out of 100 trials there would result approximately 25HH, 50Hh, and 25hh, because these combinations are governed entirely by the law of probability. It is evident that the 1:2:1 ratio is more closely approximated the greater the number of trials.

Backcrosses.—With red, white, and pink four o'clocks, six different matings are possible, as follows:

Red (RR) × red (RR)	→ 100 per cent red (RR)
White (rr) × white (rr)	→ 100 per cent white (rr)
Red (RR) × white (rr)	→ 100 per cent pink (Rr)
Pink (Rr) × pink (Rr)	→ 25 per cent red (RR), 50 per cent pink (Rr), 25 per cent white (rr)
Pink (Rr) × red (RR)	→ 50 per cent red (RR), 50 per cent pink (Rr)
Pink (Rr) × white (rr)	→ 50 per cent pink (Rr), 50 per cent white (rr)

All the preceding crosses have been considered except the last two, namely, those involving a pure (homozygous) and a hybrid (heterozygous) individual. These are called *backcrosses*. The gametes of the pure individual are all alike, but those of the hybrid are of two different kinds. Thus there are only two kinds of

zygotes that can possibly be formed, and these must occur in the same frequency. That half of the offspring resemble one parent and half the other can be easily understood by reference to Fig. 180.

Dominant and Recessive Characters.—We are now ready to consider one of Mendel's own experiments with garden peas. If tall peas are crossed with dwarf peas, or *vice versa*, the resulting

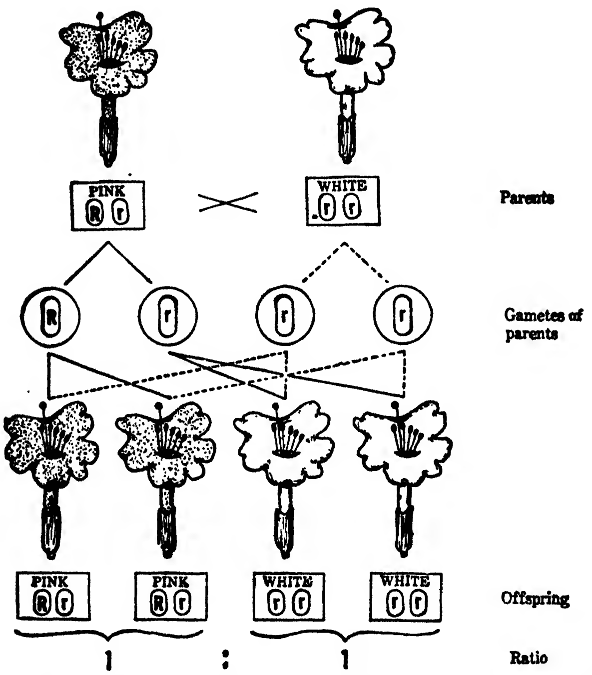


FIG. 180.—The backcross. Diagram illustrating the results of crossing a pink-flowered with a white-flowered four o'clock. Only one of the parents produces two kinds of gametes, thus resulting in a 1:1 ratio among the progeny.

hybrids are all tall, not intermediate, but no shorter than the tall parent (Fig. 181). Although genes for both characters are present in all the plants of the hybrid generation, one manifests itself to the total suppression of the other. In other words, one gene for tallness produces the same effect as if two genes were present. Mendel designated tallness the *dominant* character and dwarfness the *recessive*. Now when the tall hybrids are interbred (or allowed to self-pollinate), among the resulting

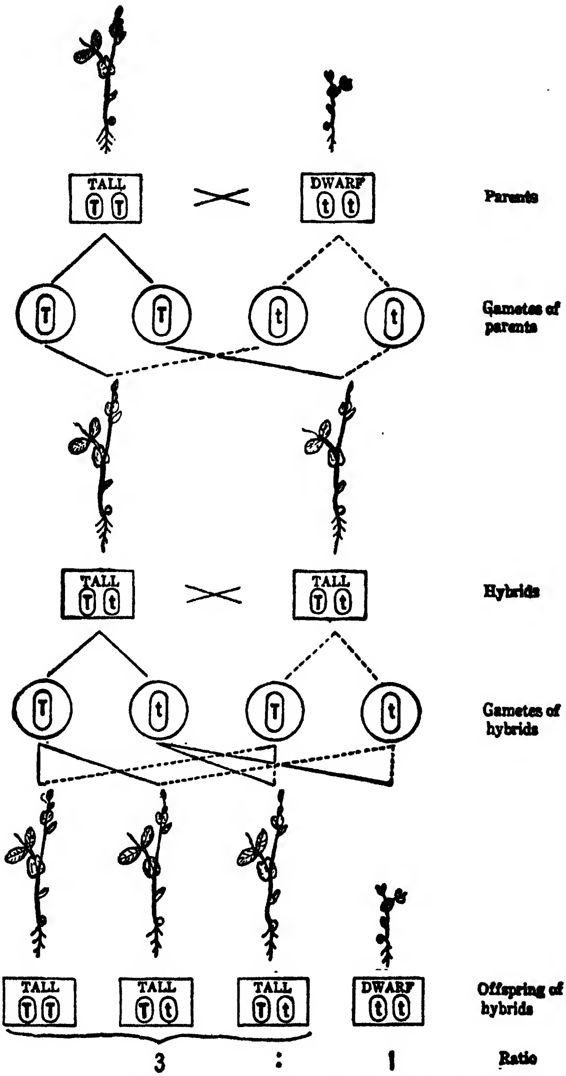


Fig. 181.—Dominant and recessive characters. Diagram of a cross between a tall and a dwarf pea, showing the history of the chromosomes carrying the genes for tallness (T) and for dwarfness (t). Because the hybrids are similar to the dominant parent, a 3:1 ratio results when they are interbred.

progeny there are approximately three tall plants to every dwarf. Because the hybrids are visibly indistinguishable from the dominant parent, however, this 3:1 ratio is really only a modification of the 1:2:1 ratio, as Fig. 181 clearly shows.

It is apparent that there are two kinds of tall individuals: pure (homozygous) tall (*TT*), and hybrid (heterozygous) tall (*Tt*), while the dwarfs (*tt*) necessarily are always pure. Although the pure and hybrid tall plants are similar to each other on the basis of outward appearance, they do not have the same breeding possibilities. Where dominance occurs, it is always possible to tell whether an organism is homozygous or heterozygous for a

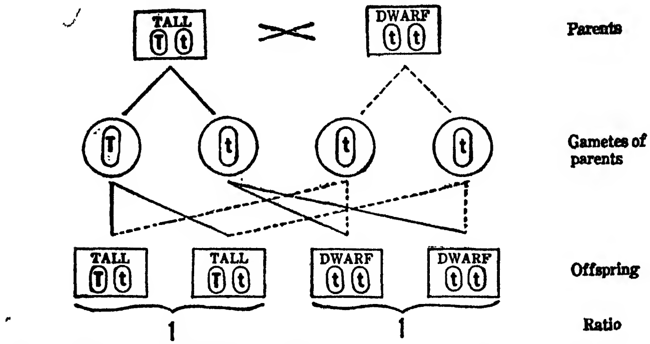


FIG. 182.—The backcross where dominance occurs. Because the parent showing the dominant character is heterozygous, half of the offspring are recessives.

given character by backcrossing it to an individual showing the contrasted recessive character. If homozygous, all the offspring will exhibit the dominant character, but, if heterozygous, only half of them will (Fig. 182).

Mendel experimented with other characters in peas, and found that purple flowers are dominant over white, yellow seeds over green, smooth seeds over wrinkled, etc. The phenomenon of dominance applies to the characters studied by Mendel and to many characters in other organisms but does not apply to most hereditary characters. The principle of segregation, however, is fundamental and always holds true. The following list contains a few characters exhibiting dominance chosen from many that are known. It also shows how widely applicable are the laws of heredity discovered by Mendel:

Organism	Dominant character	Recessive character
Indian corn	Starchy endosperm	Sweet endosperm
	Black endosperm	White endosperm
	Yellow endosperm	White endosperm
Tomato	Red fruit	Yellow fruit
	Two-chambered fruit	Many-chambered fruit
Garden pea	Tall vine	Dwarf vine
	Colored flowers	White flowers
	Green pods	Yellow pods
	Yellow seeds	Green seeds
	Smooth seeds	Wrinkled seeds
Summer squash	White fruit	Yellow fruit
	Disk-shaped fruit	Spherical fruit
Fruit fly	Red eyes	White eyes
	Gray body	Black body
	Long wings	Vestigial wings
	Bar eyes	Normal eyes
Guinea pig	Rough coat	Smooth coat
	Black coat	White coat
	Short hair	Long hair
Domestic fowl	Pea comb	Single comb
	Rose comb	Single comb
	Feathered legs	Smooth legs
Sheep	White coat	Black coat
Cattle	Polled	Horned
	Black coat	Yellow coat

Principle of Free Assortment.—The cases of inheritance that thus far have been considered are comparatively simple, for in all of them the parents differ in regard to just one pair of contrasted characters. When crossed, they give rise to *monohybrids.* Mendel also crossed peas differing with respect to two pairs of contrasted characters, thus obtaining *dihybrids*, and as a result he discovered a second important principle. If a pea having yellow smooth seeds (*YYSS*) is crossed with one having green wrinkled seeds (*yyss*), all the hybrids will have yellow smooth seeds (*YySs*) because both of these characters are dominant (Fig. 183). When these hybrids are interbred, however, four different kinds of individuals appear in approximately the following proportions: 9 yellow smooth: 3 yellow wrinkled: 3 green smooth: 1 green wrinkled (Fig. 184). The fact that two of these combinations are new shows that the two pairs of characters are inherited independently of each other.

In order to understand how this ratio arises, each pair of characters must be considered separately. It is evident that the ratio of yellow peas to green ones must be 3:1 and of smooth peas to wrinkled ones the same. Therefore the number of peas that are both yellow and smooth is determined by multiplying the number of yellow peas by the number of smooth ones (3 × 3).

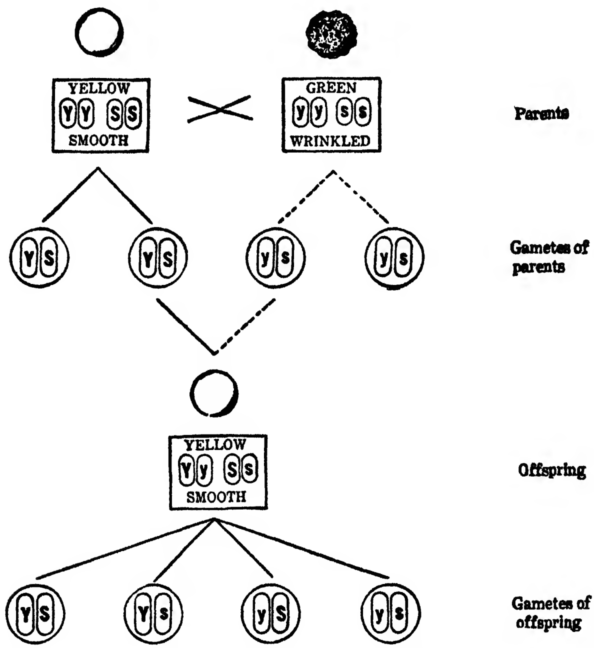


Fig. 183.—Principle of free assortment. Diagram of a cross between a yellow smooth and a green wrinkled pea. The two pairs of contrasted characters are represented by genes borne on two pairs of homologous chromosomes. The hybrid produces four different kinds of gametes.

Similarly the number of yellow wrinkled is 3 × 1, of green smooth 3 × 1, and of green wrinkled 1 × 1.

By referring to Fig. 183, it can be seen that the genes *Y* (for yellow seeds) and *y* (for green seeds) are associated with one pair of homologous chromosomes in all the vegetative cells of the hybrids, while the genes *S* (for smooth seeds) and *s* (for wrinkled seeds) are associated with another pair. Since, at the time of the reduction division, paternal and maternal chromosomes are distributed to the gametes independently of one another, there must also be *free assortment* of genes carried

on different chromosome pairs. Consequently the dihybrid peas produce four different kinds of gametes in approximately equal numbers, and each carries a different assortment of genes, as follows: *YS*, *Ys*, *yS*, and *ys*. When two dihybrids are crossed, random mating of gametes results in 16 possible unions, which, on the basis of outward appearance, fall into four classes (Fig. 184).

Although each class includes individuals that look alike, all do not have the same breeding possibilities. Thus there are four

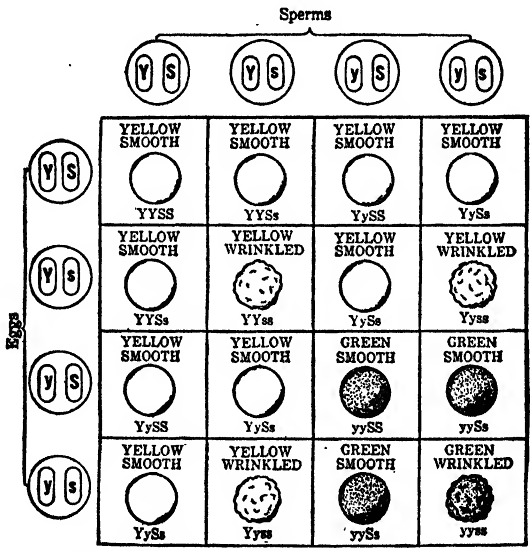


FIG. 184.—The dihybrid ratio. Diagram showing the 16 gametic unions resulting from random mating of four kinds of sperms with four kinds of eggs, giving rise to the phenotype ratio of 9:3:3:1.

kinds of yellow smooth individuals, two kinds of yellow wrinkled, two kinds of green smooth, but just one green wrinkled. Individuals with the same hereditary constitution are said to belong to the same *genotype*, while those which look alike, regardless of whether they have the same hereditary constitution, belong to the same *phenotype*. Thus from the dihybrid cross there are nine distinct genotypes, but only four phenotypes. These are given on p. 272. It should be noted that only 4 individuals out of the 16 are homozygous for both characters, and consequently these alone will breed true.

Number of individuals	Genotype	Number of individuals	Phenotype
1 2 2 4	*YYSS* *YYSs* *YySS* *YySs*	9	Yellow smooth
2 1	*Yyss* *YYss*	3	Yellow wrinkled
2 1	*yySs* *yySS*	3	Green smooth
1	*yyss*	1	Green wrinkled
Total 16	9	16	4

The principle of free assortment may be illustrated among animals by an example chosen from the heredity of guinea pigs. These animals, like many other domesticated forms, may have either colored or white fur. White animals are called *albinos*. If a black guinea pig derived from a pure stock is mated with an albino, all the offspring will be black, as colored fur is dominant to white. If the parents are alike in other respects, the simple monohybrid ratio of 3:1 arises when the hybrids are interbred; but if the parents differ in another way, such as in regard to smoothness of coat, the offspring, when interbred, exhibit the dihybrid ratio. A rough or rosetted coat is dominant to the ordinary smooth coat. Thus when a smooth black guinea pig (*rrBB*) is crossed with a rough albino (*RRbb*), the hybrid offspring will be rough black (*RrBb*), as each parent contributes one dominant and one recessive character. When these are interbred, four types appear among the progeny, approximately in the ratio of 9 rough black: 3 smooth black: 3 rough albino: 1 smooth albino (Fig. 185). The relations of these to one another are precisely the same as those of the four classes of peas shown in Fig. 184.

When there are three different pairs of contrasted characters, all showing dominance, and their genes are borne on three different sets of chromosomes, the resulting *trihybrid* produces eight different kinds of gametes. When two trihybrids are

crossed, there are 64 different gametic unions possible, giving rise to the phenotype ratio of 27:9:9:9:3:3:3:1. In the case of 10 pairs of differentiating characters, the number of possible combinations is 1,048,576. This gives some idea of the com-

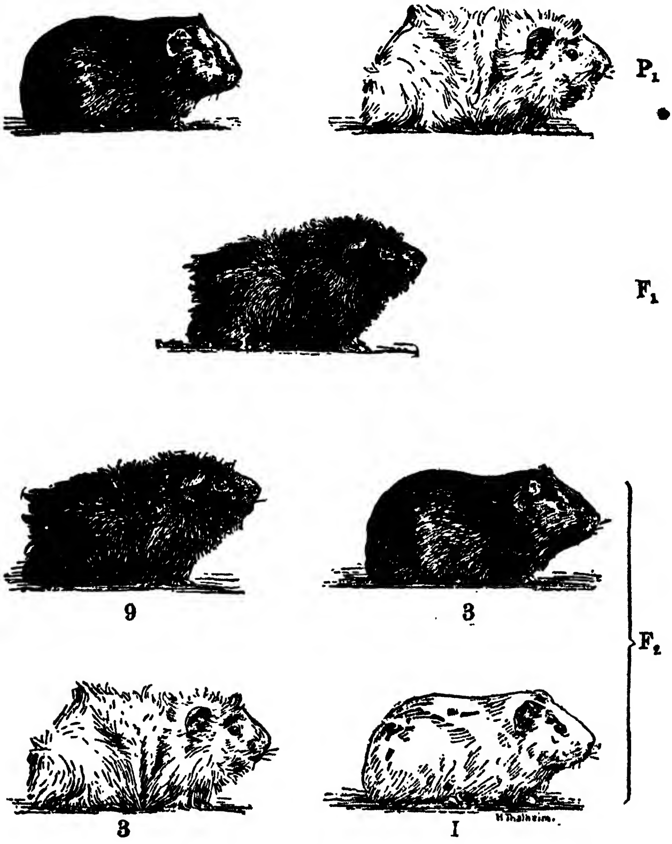


FIG. 185.—Results of crossing a smooth black with a rough white guinea pig. The hybrids (F_1) are rough black and, when interbred, produce offspring in the ratio of 9 rough black: 3 smooth black: 3 rough white: 1 smooth white. (*From Baur, "Einführung in die experimentelle Vererbungslehre," Gebrüder Borntraeger, Berlin, after Castle, by permission.*)

plexity of the hereditary mechanism. Furthermore, when it is realized that most individuals are heterozygous for many characters, we can appreciate why there is so much diversity among individuals of the same species, even among offspring derived from the same parents.

Linkage.—Free assortment occurs where different sets of genes are associated with different chromosome pairs. There is a great deal of evidence, however, indicating that each chromosome bears not one but many genes. This condition is called *linkage*. For example, in the fruit fly about 400 different characters have been studied, and yet the animal has only four pairs of chromosomes (Figs. 175 and 186). Where two genes are linked, that is, borne on the same chromosome, there is no free assortment, and so the monohybrid ratio results. Thus, in peas, if the genes *Y* and *S* were borne on one chromosome, and *y* and *s* on another, under ordinary conditions there could be no new combinations of characters, such as yellow wrinkled

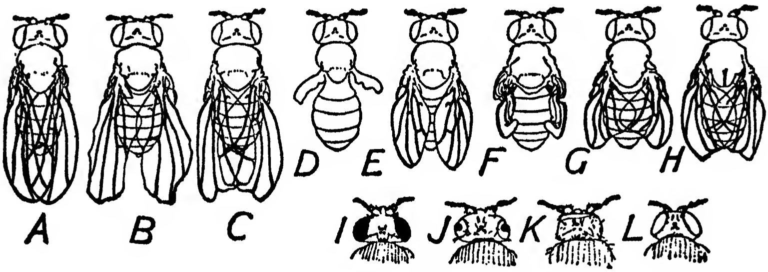


FIG. 186.—Some of the heritable variations that have arisen in the fruit fly (*Drosophila melanogaster*); *A*, normal wing; *B*, beaded wing; *C*, notch wing; *D*, vestigial wing; *E*, miniature wing; *F*, club wing; *G*, rudimentary wing; *H*, truncate wing; *I*, normal red eye; *J*, bar eye; *K*, eyeless; *L*, white eye. (*From Shull, "Principles of Animal Biology," after Morgan, et al.*)

or green smooth. All yellow peas would be smooth and all green ones wrinkled. However, owing to an occasional peculiarity in the behavior of the chromosomes at the time of the reduction division, called "crossing over," linked genes often become separated from one another and come to lie on different chromosomes. When homologous chromosomes are associated in pairs, sometimes a portion of one is interchanged with the corresponding portion of the other. Then, when the two chromosomes separate, each has received from the other a group of genes that it did not have before.

Linked characters tend to be inherited together because their genes are carried by the same pair of chromosomes. It has been found that, in the fruit fly, all of the genes which have been studied fall into four groups corresponding to the four pairs of chromosomes (Fig. 187). Although the genes in different

groups show independent assortment, those in the same group show linkage. Moreover, there is considerable evidence indicating that the genes on each chromosome are arranged in a linear

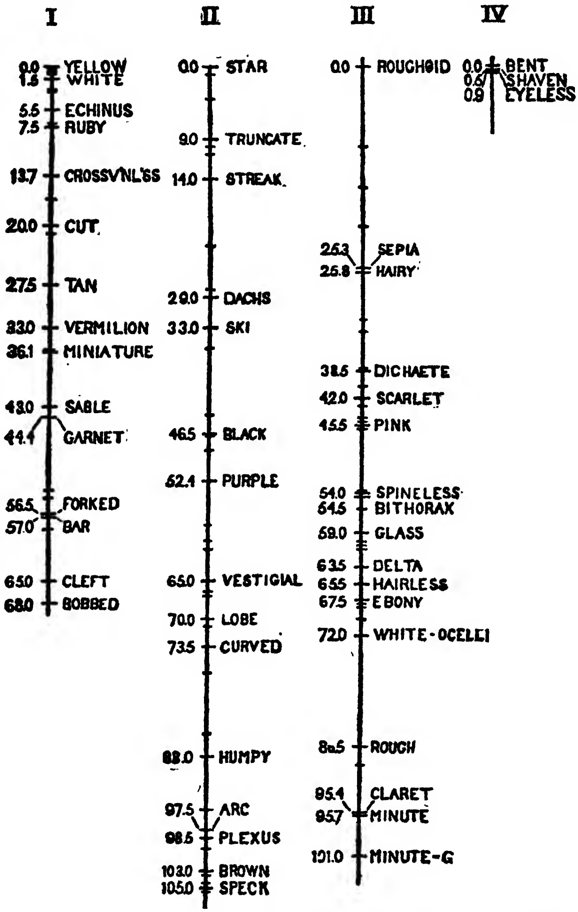


FIG. 187.—Chromosome map of *Drosophila melanogaster*, showing the location of some of the genes that have been studied. These fall into four groups, I, II, III, and IV, corresponding to the four pairs of chromosomes. The names indicate the characters in the fly with which these genes are associated; the numbers represent the distance of the locus of each gene from one end of the chromosome. (*From Morgan, "Evolution and Genetics," Princeton University Press, by permission.*)

series. Actually, in the fruit fly it has been possible, through hereditary behavior, to determine the relative position of the genes on each chromosome with reference to one another, as

indicated in Fig. 187. Proof that each gene is always situated on a particular chromosome, and at a definite locus on the chromosome, has been one of the outstanding accomplishments of modern genetics.

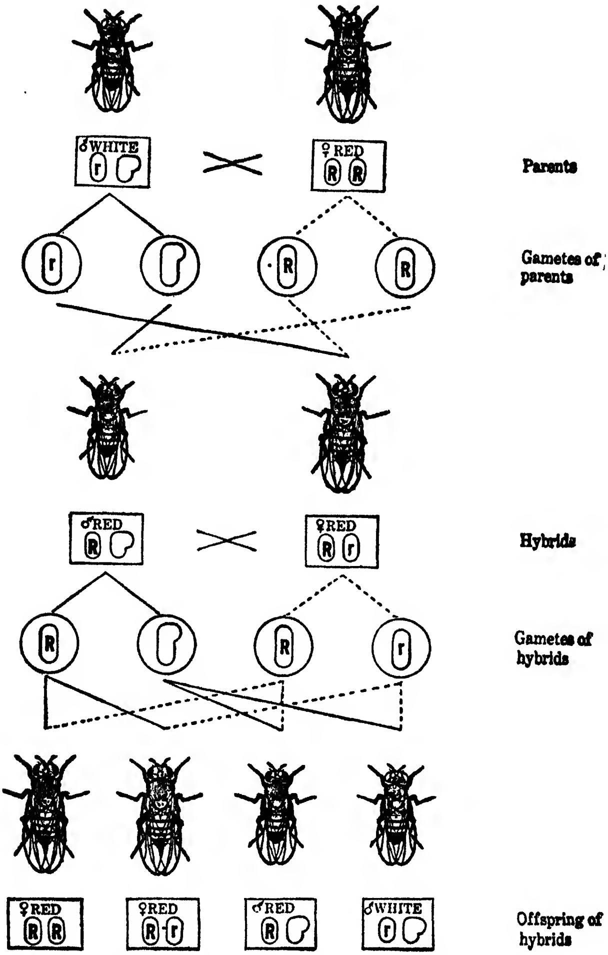


FIG. 188.—Diagram of a cross between a white-eyed male and a red-eyed female fruit fly, illustrating sex-linked inheritance. The genes for eye color are associated with the X-chromosomes. (*Adapted from Morgan.*)

Sex-linked Inheritance.—In many animals there are hereditary characters that are transmitted in a unique way. This is due to the fact that their genes are carried by the X-chromosomes.

Such characters are termed *sex linked.* The inheritance of white eye color in the fruit fly is a well-known example.

When a male fruit fly with white eyes is mated with a red-eyed female, all the offspring are red eyed, showing that red is the

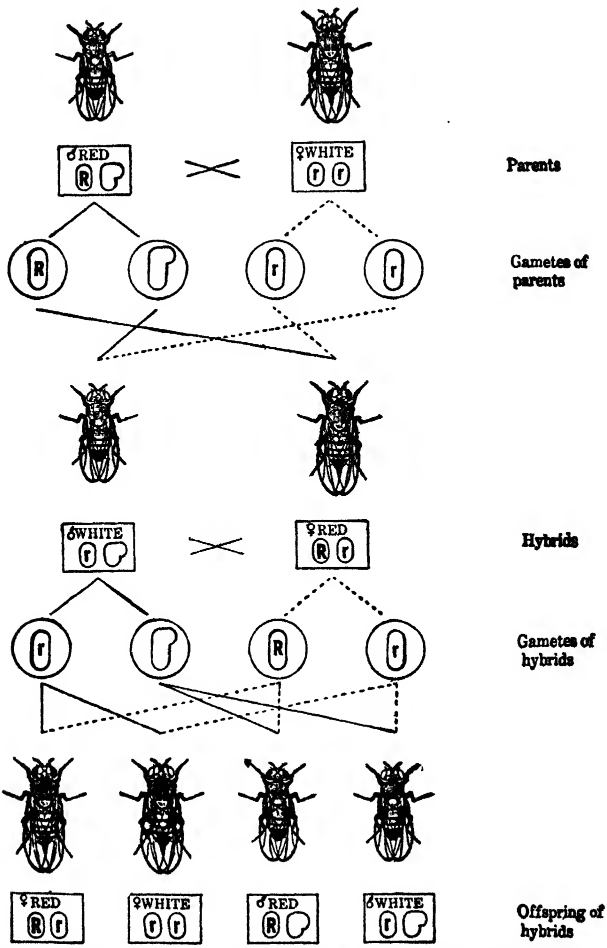


FIG. 189.—A red-eyed male crossed with a white-eyed female fruit fly, the reciprocal of the cross shown in Fig. 188. (*Adapted from Morgan.*)

dominant character. When these individuals are interbred, however, all the female progeny have red eyes, while half of the male are red eyed and half white eyed (Fig. 188). The typical monohybrid ratio of 3:1 appears, but invariably the

white-eyed individuals are males. These results are easily understood if it is assumed that the gene for red eye color is carried by the X-chromosomes, and that the Y-chromosome does not carry any genes.

When the reciprocal cross is made, that is, a red-eyed male mated with a white-eyed female, all the sons have white eyes

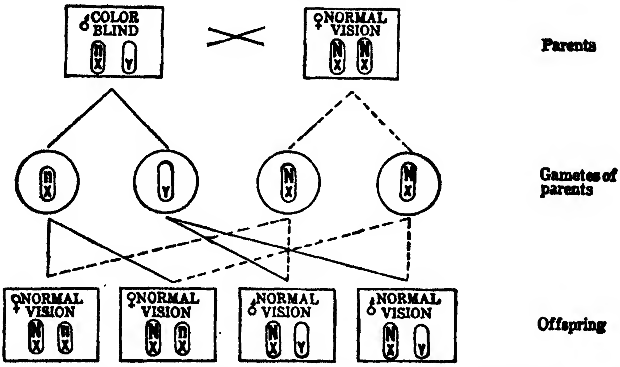


FIG. 190.—Diagram of the inheritance of human color blindness through the male. The offspring are all phenotypically normal, but the daughters are heterozygous for the defect.

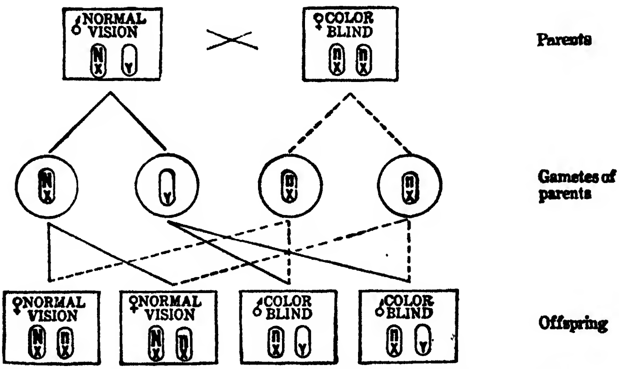


FIG. 191.—Diagram of the inheritance of human color blindness through the female. A color-blind woman has color-blind sons and normal daughters, but the latter are heterozygous for the defect.

and all the daughters red eyes (Fig. 189). But when these hybrids are interbred, their offspring fall into the following classes: 1 red-eyed female: 1 white-eyed female: 1 red-eyed male: 1 white-eyed male.

The type of sex linkage described above occurs in many other insects, in certain fishes and amphibians, in sheep, cats,

man, and probably in most mammals. In butterflies and moths, in birds, and in some fishes, the inheritance of sex-linked characters is exactly the reverse, because here the male has two X-chromosomes, the female only one (see p. 259).

Color blindness in man is a sex-linked character that follows the same scheme of inheritance as white eye color in the fruit fly. Color blindness is recessive to its contrasted character, normal vision. A color-blind man, mated to a normal woman, transmits a gene for the defect to all his daughters, but to none of his sons (Fig. 190). Since the character is recessive, none of the daughters are themselves color blind, but are merely heterozygous, having but one gene for the defect. Such women are called "carriers." A color-blind woman, on the other hand, mated to a normal man, transmits the defect to all her sons (Fig. 191). Because the gene for color blindness is carried by the X-chromosome (the Y-chromosome being not involved at all), males are either normal or actually color blind, while females may be either normal, color blind, or heterozygous for the character. Color blindness in women occurs in about 4 cases per 1,000 as compared with 40 cases per 1,000 for men. Color blindness in women is very rare, because it depends upon the mating of a color-blind man to a woman who is either herself color blind (homozygous) or a carrier for the defect (heterozygous), and this seldom happens.

CHAPTER XVII

APPLICATION OF HEREDITARY PRINCIPLES

With the rediscovery of Mendel's laws in 1900, a great impetus was given to the study of heredity, and as a result a large mass of facts has been accumulating ever since. The mechanism of hereditary transmission has been studied in many different organisms, and it has been found that the fundamental features of Mendelism are practically universal in their application. It should be understood, however, that heredity is a much more complex matter than our elementary consideration of it has indicated. For example, many characters are determined by several or many genes which interact with one another to produce a given result, while in other cases one gene may control the development of several characters. Another complication arises from the fact that the mode of expression of characters is often subject to environmental influences. Consequently in an elementary course it is not possible to present more than a very general background of information pertaining to heredity, as has been done, or to touch upon its application to human interests except in a very superficial way.

PLANT AND ANIMAL BREEDING

The improvement of plants and animals must have started soon after primitive man began to raise crops and to bring wild animals under domestication. But although the art of breeding has been practiced from time immemorial, it has been on a scientific basis only since our modern knowledge of genetics has developed. Plant and animal breeding is an extensive subject that can be discussed here only in its barest outline, giving attention chiefly to the methods that modern scientific breeders use in developing improved races.

Variation.—Common observation demonstrates that all kinds of organisms show considerable diversity among themselves; in

fact, no two individuals of any species are exactly alike in all respects. It is by reason of this fact of universal variability that it is possible for plants and animals to be improved under man's guidance. The differences between individuals are called *variations.* Although it may seem that all variations are capable of being transmitted from parent to offspring, such is not the case, and consequently the existence of both heritable and non-heritable variations is recognized. To the latter class belong most differences that arise through the direct action of environmental influences and through use and disuse. Although such induced changes may be profound, there is practically no evidence that they are transmitted to subsequent generations (see pp. 389–393). On the other hand, variations that are inherent—that are determined by the germinal constitution of the organism—are of course transmissible. It is only heritable variations that are important to the breeder, as they alone make racial improvement possible. Of the great host of characters in cultivated plants and domesticated animals that are determined largely by heredity, the following may be mentioned: vigor and rate of growth, yield, size and shape of parts, hardiness, color of flowers, quality of fruits, disease resistance, drought resistance, milk production in cattle, and egg production in poultry.

The multitudinous races of plants and animals that serve human needs have been developed by selection, hybridization, or a combination of the two. The two chief methods of selection in common use are *mass culture* and *pedigree culture.*

Mass Culture.—This is a method of selection used only with plants. It is the oldest method of plant breeding, and, although it has been more or less replaced by other methods, it is still of considerable value. Mass culture involves breeding from a selected group of individuals, a group that varies in some desirable direction, such as greater yield, larger fruits, brighter flowers, etc. Seed is collected from these superior individuals and sowed *en masse.* The selection process is continued with each generation until an improved race of plants is developed. Mass culture has been widely used in the breeding of corn and cotton, as well as a number of other crop plants. Although mass culture has certain advantages, its limitations should be kept in mind. These are as follows:

1. In most cases it is necessary to continue the process of selection indefinitely; otherwise the improved strain deteriorates.

2. Mass culture cannot produce new characters but merely improves such characters as already exist.

3. It does not isolate the best individuals but merely raises the average quality of a large group.

4. Selection is made entirely on the basis of outward appearance, which, in heterozygous individuals, is often deceptive, as has been seen.

5. The selected individuals, in many cases, owe their superior qualities to environmental factors, and such variations have no permanent racial value.

6. Mass culture is a slow method, the progress made in each generation being slight.

Pedigree Culture.—This method of breeding has long been applied to animals, but only rather recently to plants. It involves the selection of single plants, each of which is made the basis of a separate race. Seeds from each selected individual are planted in an isolated plot in order to prevent intercrossing. An exact record, or pedigree, is kept of the progeny of each selected individual, and after several generations the best strain is preserved and made the basis of an improved variety, the others being discarded. Thus selection is made on the basis of hereditary behavior, not merely on outward appearance.

The pedigree method of breeding results in a much greater degree of uniformity among the members of the improved race than where mass culture has been used. In fact, in many cases the offspring of the originally selected individual show so little variation that further selection is unnecessary. All that is required is to prevent the plants of the improved race from crossing with inferior stock. The new variety will breed true if the plant that was originally isolated is homozygous for the superior characteristic or quality that it is desired to preserve; otherwise not all the progeny will be superior.

Pedigree culture is valuable as a means of preserving *mutants* or "sports." This term is applied to individuals strikingly different from the others—individuals that appear spontaneously. In nearly all cases they breed true for their peculiarities if isolated. Examples of mutants are plants bearing seedless fruits (which must be propagated vegetatively), double flowers,

purple leaves, etc., and animals without tails, without horns, with loss of pigment (albinos), etc. Many new varieties of plants and animals have arisen as "sports."

Pedigree culture is best adapted to plants that are normally self-pollinated and has been used very successfully with such plants as wheat, oats, peas, beans, tobacco, and potatoes. With corn and certain other cross-pollinated plants, the isolation of individuals and the development of homozygous strains result in a marked loss of vigor, and hence the pedigree method is not applicable to such cases.

It is apparent that in animal breeding two individuals must necessarily be selected as the basis for an improved strain, and both must have the superior character. Knowledge of the hereditary constitution of the selected individuals is available in their recorded pedigree. Although it is generally not advisable to mate the offspring of a single pair of parents, much inbreeding is necessary as a means of preserving a particular set of characters. Consequently all members of an improved stock are usually more or less closely related.

The older method of breeding was to judge an animal entirely on the basis of appearance or performance; the newer method is to consider its relatives as well. Its appearance may or may not be an index of its breeding possibilities. Thus the value of an animal for breeding purposes depends on its pedigree.

Hybridization.—The method of hybridization is used extensively in both plant and animal breeding. A hybrid has been defined as an organism whose parents represent two distinctly different types of individuals. Although, as a rule, only closely related organisms can be crossed, many hybrids have been produced by crossing individuals belonging to distinct species or even to different genera. In some cases, however, the progeny resulting from a wide cross are sterile, the best-known example being the mule, produced by mating a jackass with a mare.

The chief value of hybridization is that it brings together characters to form combinations that did not occur previously. Because a desirable combination depends upon chance, usually a great many crosses of the same kind have to be made. Hybridization is particularly useful as a method of plant breeding where vegetative multiplication is possible, as then the hybrid can be propagated without using seeds. The advantage is obvious, for

without sexual reproduction there can be no segregation of genes, and so the characters of the hybrid can be preserved indefinitely. Where sexual reproduction is necessary, as in many plants and in all domesticated animals, the situation is far more difficult. Because segregation occurs when the hybrids are interbred, the members of the next generation are exceedingly diverse and represent all kinds of new character combinations. If some of these represent what is desired, they may be isolated and raised under pedigree culture, selection being continued until a pure-breeding race is obtained.

Another value of hybridization is to increase vigor. Many hybrids are more vigorous than either of their parents. Hybrid vigor may express itself in more rapid growth, in larger parts, in greater resistance to adverse conditions, or in other ways. For example, Burbank's "royal walnut," a cross between the California walnut (*Juglans californica*) and the black walnut of New England (*Juglans nigra*), grows twice as rapidly as either parent and greatly exceeds them in height. In corn, hybrids may yield as much as 50 per cent more grain than the average yield of their parents. Among animals, hybridization results in greater vigor in hogs, cattle, horses, sheep, dogs, and probably many others.

EUGENICS

The science of *eugenics* was founded by Francis Galton (1822–1911) and was defined by him as "the study of agencies under social control that may improve or impair the racial qualities of future generations, either physically or mentally." It is an attempt to apply to man the same principles of scientific breeding that have been so effectively used in the improvement of plants and animals. In other words, eugenics is an effort to control human evolution by selective mating. Most of the agencies concerned with the improvement of man—education, religion, medicine, philanthropy, etc.—deal primarily with environmental factors; they seek to improve the surroundings. Although these influences are indispensable, it should be realized that they affect only the individual, not the race. Man cannot be improved racially by improving the environment any more than a breeder can create prize winners from scrub stock by giving them the best of food and care.

Heredity and Environment.—The relative importance of heredity and environment in the development of an individual has long been a matter of controversy. Until recent years it has been rather generally assumed that environmental influences are of the greater importance, and many people still have this opinion. That all men are born equal and that the nature of the surroundings determines the characteristics an individual comes to have are old ideas.

Modern biology teaches that the more powerful influence in determining the constitution of an organism is heredity, but that environment has an important part to play in the final expression of adult characteristics and qualities. Our innate capacities and tendencies are fixed by heredity. The environment merely determines how they shall develop, that is, what we shall do with our natural gifts. Thus, for the most part, the environment is a guiding influence, not a creative one. Capacities for improvement are inherited, but improvement itself depends upon the presence of favorable circumstances. Environment merely gives an inherent tendency an opportunity to develop along lines predetermined by heredity. One may inherit exceptional musical ability, but, in the absence of an opportunity for sound training, it may never express itself. On the other hand, no amount of training can create a musician from a person with no natural aptitude in this direction.

The study of twins furnishes strong evidence as to the greater importance of heredity in development. As Galton first showed, and others have later substantiated, when identical twins (see p. 260) are separated in early life and each is brought up under a different set of surroundings, their resemblances in both mind and body persist. On the other hand, when fraternal twins, which always have a different set of hereditary characters, are brought up under exactly the same set of environmental influences, the dissimilarity between them does not diminish but usually increases as time goes on.

Hereditary Characters in Man.—The study of human heredity presents a number of difficulties, and the results are less certain than those obtained with the lower animals. There are several reasons for this. (1) Man is more complex, especially mentally, than any of the lower animals and subject to a much greater set of environmental influences. (2) Experimental breeding is not

possible, and consequently we must rely for information upon family records and other vital statistics. (3) Such data are often incomplete and unreliable and even at best show only average conditions. (4) Every individual represents a complex mixture of many hereditary lines. (5) The production of relatively few offspring makes it difficult to obtain ratios indicating the chances involved and to determine what all the hereditary possibilities may be in any given mating.

Although many human characters are known to be heritable, much uncertainty exists regarding their mode of transmission, and those concerning which we have the greatest amount of information are mostly abnormal or defective characters. A brief list is given below of some of the hereditary characters in man:

Dominant	Recessive[1]
Dark hair	Blonde hair
Brown eyes[2]	Blue eyes
Hereditary cataract	Normal eyes
Normal pigmentation	Albinism
Brachydactyly (short digits)	Normal digits
Polydactyly (extra digits)	Normal digits
Syndactyly (fused digits)	Normal digits
Normal	Hereditary feeble-mindedness
Normal	Hereditary epilepsy
Normal	Hereditary insanity
Normal	Congenital deaf-mutism
Normal	Left-handedness
Normal	Hemophilia (profuse bleeding)[3]
Normal	Color blindness[3]
Normal	Night blindness[3]

[1] In a few of the cases listed here it is a slight overstatement to say that one of the characters is recessive. The case is not quite so simple.

[2] Including green, hazel, and all other shades but pure blue.

[3] Sex-linked (see p. 276).

The following characters are blending in their inheritance, and in most cases arise from the action of several independently inheritable genes: general body size, stature, weight, skin color, hair form (degree of curliness), shape of head, facial features, etc.

A great many characters are known to be largely determined by heredity, but the mode of their inheritance is uncertain. Some of these are: general mental ability, memory, temperament, musical ability, artistic ability, literary ability, mechanical

ability, nearsightedness, astigmatism, allergy, baldness, tendency to produce twins, and longevity.

Aims of Eugenics.—Eugenics has two definite aims or purposes: (1) to eliminate undesirable qualities from the race by preventing the breeding of defectives; (2) to increase the proportion of superior strains in the general population by encouraging matings between highly endowed individuals. In both of these ways the average quality of the race may be kept from deteriorating. The urgent need of eugenics is apparent when it is realized that the present rate of reproduction among the mentally superior individuals is unusually low, among the mentally inferior, unusually high. The highest birth rate exists among the classes having the least value to society. It is the principal object of eugenics to discover the causes underlying this deplorable situation and to seek means of remedying it.

Elimination of Defectives.—By defectives is meant not only the feeble-minded and insane, but criminals, paupers, tramps, beggars, and all other persons who are a burden to society. Although many of these are confined to prisons, asylums, almshouses, and similar institutions, a great many defectives are at large, free to propagate their kind. For example, it has been conservatively estimated that there are between 400,000 and 800,000 feeble-minded persons in the United States of which perhaps only one-tenth are confined in institutions. Although most of these people are not a direct menace to society individually, as a class they are reproducing at a higher rate than normal persons.

Although many defectives may be the victims of a poor environment and owe their unfortunate condition largely to this fact, there is no question but that most defectives are mentally deficient and simply lack the capacity for improvement. Feeble-mindedness results from a failure of the mind to continue its normal development, the intelligence of the individual remaining child-like. Some cases of feeble-mindedness may be caused by accident or disease, but it has been found that at least 60 per cent of them are due to an inherited tendency and cannot be corrected. The condition is a complex one, probably representing a combination of several defects. For the most part, it seems to be inherited as a simple Mendelian recessive. There is also ample evidence that many forms of insanity are inherited. Although

insanity seems to be a recessive character, the exact mode of its transmission is not understood. This is due to the unreliability of the data, to the fact that the condition may be greatly modified by the environment, and because the term is used to cover a great variety of disordered nervous conditions.

Because most human defects, both physical and mental, seem to be recessive, they may become latent in many strains without their presence being suspected. Consequently two normal individuals, both heterozygous for the same defect, may produce some abnormal children. For this reason, intermarriage among families having hereditary defects is to be condemned. Defectives tend to intermarry, however, because they are largely avoided by normal persons.

The tendency to commit crimes is closely associated with feeble-mindedness, many criminals being mentally defective. The same is true of paupers, drunkards, prostitutes, etc. Mental tests performed on juvenile criminals in state "reformatories" have shown 50 to 90 per cent to be feeble-minded.

As a means of eliminating defective members of society, a number of plans have been suggested, but many of these are not practical. The tendency has always been to protect and care for the unfit, to give them every opportunity to improve, and except in extreme cases to grant them the same "personal rights" as normal individuals. The result has been a constant multiplication in numbers. An attempt has been made to meet the situation by legislation, but laws cannot be made effective except in a limited number of cases. Our present immigration laws keep defectives from entering the country but are inadequate because many immigrants who appear to be normal carry latent hereditary defects, that is, are heterozygous. It is evident that if defectives are prevented from leaving offspring, the inferior strains will eventually die out. Laws preventing the marriage of defectives, however, have no effect, as the percentage of illegitimate births among the socially worthless is very high. Laws compelling the segregation of the sexes in institutions are effective if enforced, but the most satisfactory plan is sterilization. In the male this is accomplished by a very simple operation (*vasectomy*) performed under a local anesthetic and involving no risk to health, but in the female a similar operation (*salpingectomy*) is attended with as much inconvenience and danger as any

other abdominal operation. In both operations the ducts through which the reproductive cells must pass are severed and sealed. In neither case, however, is there any interference with normal instincts or functions, except that reproduction is made impossible.

Although sterilization is the only certain way of preventing the breeding of defectives, public sentiment is not yet sufficiently enlightened as to the necessity of enacting and enforcing rigid sterilization laws. About 30 states have such laws at the present time, but some seldom put them into operation. Up to the end of 1938, the total number of eugenic sterilizations performed in state institutions has been only 30,690, nearly half of which have taken place in California.

Increase of Superiors.—That superior mental ability runs in families was first proved by Galton and is accepted today as a fact. Not only is general intellectual capacity inherited but also special aptitudes for music, art, literature, etc. Although we recognize the fact that these and many other mental qualities are inherited, we know little concerning the manner of their transmission.

It has been pointed out that the birth rate among the intellectual classes is lower than among the population as a whole, so low in fact, that they are not maintaining themselves. No class can persist indefinitely unless there is an average of 3.7 children per family, and the superior stocks do not average two. For example, it has been shown that only half of the graduates of women's colleges marry as compared with over 90 per cent of all women, while but three-fourths of the graduates of men's colleges marry. The graduates of coeducational institutions average only 5 to 9 per cent higher.

The low birth rate of superiors is largely due to economic factors, not to inherent infertility. Late marriage is unquestionably an important cause; this arises chiefly from the necessity of obtaining an education. The high cost of maintaining modern standards of living is also a vital factor in reducing the number of children, while luxury and selfishness must be added as a third factor, as many people have no desire for children.

CHAPTER XVIII

ADAPTATION

In making a detailed study of any plant or animal, one is impressed with the striking correlation that exists between the structure of its various organs and the functions they perform. As has been seen, structural differentiation has come about through a specialization of different parts of the body for particular kinds of work. A root, for example, owes its distinctive features to the fact that it anchors the plant in the soil, absorbs water therefrom, and carries it to the shoot system. A leaf, on the other hand, exhibits a totally different form and structure because its functions are different, the leaf being primarily fitted to carry on the work of photosynthesis and to regulate transpiration. The same correlation between structure and function is also everywhere apparent in the animal body. The structure of the heart has significance only when we understand its mode of action, and the same is true of the stomach, an eye, a limb, or any other part of the body.

Not only is every organ, by reason of its structure, fitted to perform certain definite functions, but a marked three-fold relation exists between structure, function, and environment. One of the most obvious facts in nature is that organisms are suited to their surroundings—to the great complex of external conditions under which they live. An organism is related not only to light, air, water, temperature, etc., but to other organisms as well. The former set of factors constitutes the *inorganic environment*, the latter, the *organic environment*. The branch of biology that deals with the life relations of organisms, that is, with their relations to the conditions under which they live, is called *ecology*. The marvelous adjustment exhibited by all organisms between structure, function, and environment is what ordinarily is implied by the term *adaptation*. It is the fitness of organisms to their conditions of life and the fitness of their parts to the functions they perform.

The structural differences displayed by organisms living under diverse sets of external conditions are largely correlated with the conditions themselves. Any set of conditions capable of supporting life constitutes a *habitat*, and in any given habitat only such plants and animals can live as are adapted in structure and function to meet the particular conditions that characterize it. Ponds, rivers, seashores, meadows, swamps, prairies, forests, deserts—each has its own distinctive fauna and flora. This arises from the fact that organisms which occur in the same habitat have similar life requirements, and these are largely fulfilled by the nature of the local conditions. Thus the plants and animals living in an alpine habitat are unlike lowland forms, chiefly because the environmental conditions in the two places are dissimilar. For the same reason, tide-pool animals are not found in the deep sea, or the plants of a moist meadow upon the desert. The most important factors governing the distribution of plants into various kinds of habitats are chiefly those arising from differences in soil and climate. In animals the nature and abundance of particular kinds of food are perhaps of major importance, although physical factors also play a prominent role.

The term "adaptation" is applied not only to the fact of fitness, but to adaptive characters themselves. Some characters, especially the trivial ones that often serve to distinguish closely related species from one another, have no obvious adaptive significance, but most of the basic features of plants and animals do show a relation to the environment. In general, the appearance of characters in an organism is dependent upon the presence of a particular set of hereditary factors in the chromatin of all of its body cells, and although the final expression of many characters may be influenced by certain environmental factors, for the most part the surroundings themselves do not cause an organism to develop adaptive features. These arise, like most other characters, through the great internal influence—heredity. Thus nearly all adaptations are racial, that is, inborn in the organism.

RACIAL ADAPTATIONS

We are now ready to consider a few conspicuous examples of racial adaptations—cases where an intimate relation between structure, function, and environment has been largely determined by the organism's ancestry. Since every individual has

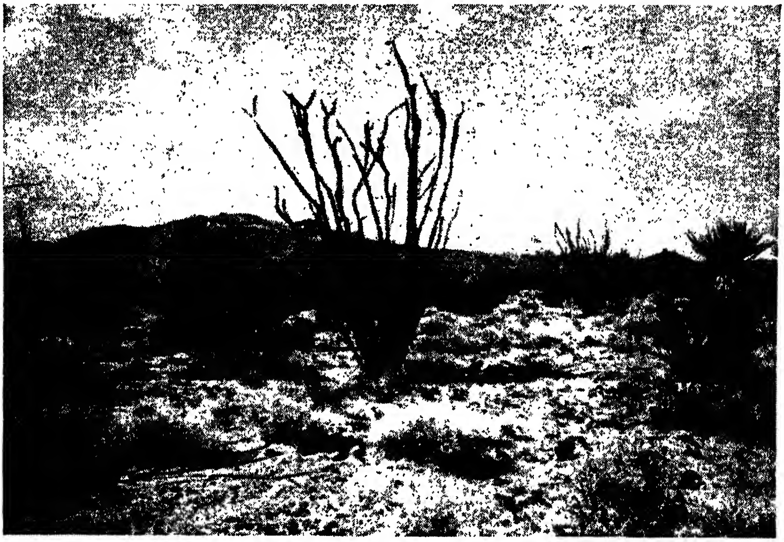


FIG. 192.—Desert vegetation in western Arizona.

FIG. 193.—A thick-leaved desert plant (*Agave deserti*), the fleshy leaves serving as reservoirs for the accumulation of water.

been called a "bundle of racial adaptations," many more examples will be suggested by the few that are given.

Desert Plants.—Plants that live in deserts exist under a set of very severe conditions, *viz.*, intense light, high temperatures,

Fig. 194.—A barrel cactus (*Echinocactus cylindraceus*). The green, thickened, longitudinally fluted stem stores water and carries on photosynthesis, no leaves being present.

dry air, dry soil, and often strong winds. Only such plants can live there as are structurally adapted to endure these rigorous conditions (Fig. 192). It is evident that the greatest problem of the desert environment is the conservation of water, and this is solved by desert plants both by increasing absorption and retard-

ing transpiration. Various structural adaptations bring about the same results in different cases, as the following examples show.

Many desert plants have a very deep root system that enables them to absorb water from a great depth. Others have a shallow root system but a very extensive one. In most desert plants the

FIG. 195.—Cross section of a leaf of oleander (*Nerium*), a plant adapted to live in dry air, × 200. Note the thick cuticle, the several layers of epidermal cells, upper and lower palisade tissue, and stomata in pits protected by epidermal hairs.

leaves are small, often being developed as mere scales or spines. Reduction of leaf surface effectively lessens transpiration but, at the same time, hinders photosynthesis. As a compensation, many small-leaved and almost leafless desert plants have green stems, as in the cacti. Another adaptation seen in many desert plants is the development of water-storage tissue, either in the leaves, as in the aloe and agave, or in the stems, as in the cacti (Figs. 193 and 194). Many plants of dry regions have hard stiff leaves with an

unusually thick cuticle, which acts as a check against transpiration. In such cases the stomata are generally sunken below the level of the leaf surface and often are confined to pits (Fig. 195). The presence of a thick covering of hairs, characteristic of many desert plants, is also thought to be related to the conservation of water. Hairs are outgrowths from the epidermal cells.

Desert plants are peculiar because they live under a set of extraordinary conditions. They are structurally adjusted to meet these conditions, and for the most part their distinctive features are racial, not acquired. Thus when most plants of dry regions are grown under ordinary garden conditions, they retain their desert characteristics.

Seed Dispersal.—The seeds of many plants are adapted to be disseminated by some particular agency, the two most important ones being wind and animals. Trees such as the elm, ash, maple, and catalpa have winged seeds[1] adapted to dispersal by the wind (Fig. 196). In falling to the ground the wing presents a flat surface to the air, in some cases causing the seed to spin around and thus retard its descent. A strong wind might carry such a seed a considerable distance from the parent plant. The dandelion, thistle, milkweed, cottonwood, and many other plants have downy seeds; a tuft of cotton or down acts as a parachute and keeps them suspended in the air for a long time. Such seeds are often carried great distances by the wind. The seeds of the various kinds of "tumbleweeds," such as the Russian thistle, are dispersed by the wind in another way. These plants grow on open plains. By an incurving of the branches the plant assumes a spherical form. When the seeds are ripe the entire plant breaks off at the ground and is blown about by the wind, dropping its seeds as it moves along.

Animals carry seeds in several different ways. The barbed appendages of the cocklebur, burdock, and various kinds of "stick-tights" serve as a means of attachment to the bodies of animals (Fig. 197). Many marsh plants owe their wide distribution to the fact that their seeds are carried in the mud that clings to the feet of wading birds. Fleshy fruits, particularly brightly colored ones and those attractively flavored, are eaten in great numbers by various kinds of birds and mammals.

[1] In some of these and the following examples, the "seeds" are really small, dry, one-seeded fruits, but this distinction is of no significance here.

Often the seeds are voided without being swallowed, but in many cases when swallowed they pass through the body unaffected by the digestive fluids.

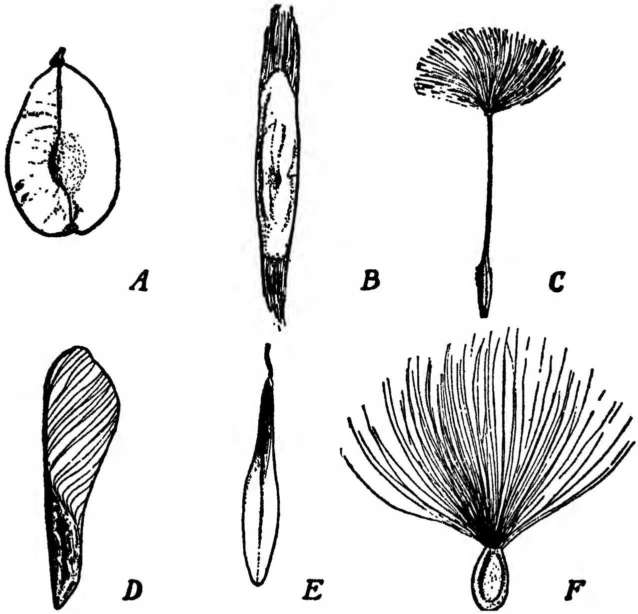


FIG. 196.—Seed dispersal by wind. *A*, winged fruit of elm; *B*, winged seed of catalpa; *C*, downy fruit of dandelion; *D*, winged fruit of box elder; *E*, winged fruit of ash; *F*, downy seed of milkweed. (*C*, × 2; others, × 1.)

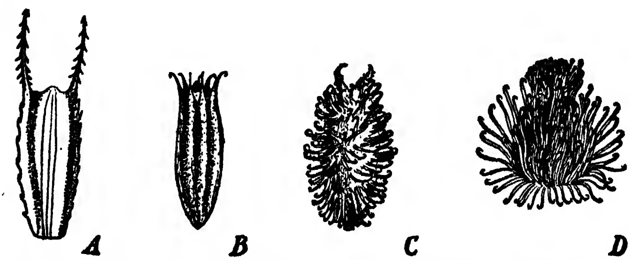


FIG. 197.—Seed dispersal by animals. *A*, beggar ticks; *B*, horehound; *C*, cocklebur; *D*, burdock. (*A* and *B*, × 2; *C* and *D*, × 1.)

Insect Pollination.—Flowers are either *self-pollinated* or *cross-pollinated,* depending upon whether each flower pollinates itself or whether pollen from one flower is transferred to the pistil of another flower. Cross-pollination is brought about chiefly by wind or by insects. Self-pollinated flowers and those cross-

pollinated by the wind are usually inconspicuous and odorless, while most flowers cross-pollinated by insects have white or brightly colored corollas or an attractive fragrance. Insects visit flowers chiefly to get nectar from them, the act of pollination being purely an incidental matter. Nectar is a sweet liquid secreted by glands situated inside the flower, either at the base of the petals (Fig. 61) or in a special sac or spur (Fig. 198). Insects gather nectar as food, either for themselves or for the larvae. In getting nectar from a flower, some part of the insect's body comes in contact with the stamens and is covered with pollen. This is then carried to the next flower where some is rubbed off on the stigma. In this way cross-pollination is accomplished. It should be understood that there is nothing intentional in this behavior on the part of the insect. It unavoidably carries pollen in going from flower to flower in search of food.

FIG. 198.—Flower of garden nasturtium (*Tropaeolum*) cut through the middle to show the spur (*s*) and the nectary (*n*), natural size.

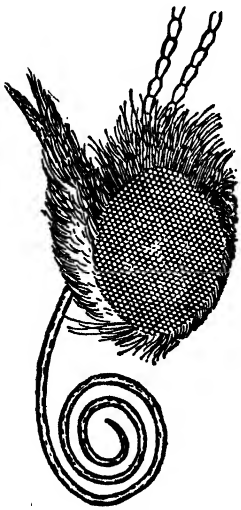


FIG. 199.—Side view of head of butterfly, showing coiled proboscis. (*From Sanderson and Jackson, "Elementary Entomology," Ginn and Company, by permission.*)

Butterflies and moths obtain nectar for their own use, as the caterpillars are not fed by the adults. The mouth apparatus of a butterfly consists of a very long tube called a *proboscis*, which when not in use is coiled under the head like a watch spring (Fig. 199). Flowers that are adapted to be pollinated by butterflies or moths, such as the tobacco, petunia, honeysuckle, pink, etc., have a tubular or funnel-shaped corolla at the bottom of which nectar collects (Fig. 200). The stamens are situated at the mouth of the corolla. Such flowers are largely dependent upon butterflies or moths for their polli-

nation, as these insects are particularly adapted to reach the nectar.

Bees gather both nectar and pollen, which they feed to the larvae. In many bees a portion of the hind legs serves as a "pollen basket" in which pollen is carried to the hive and fed to the larvae (Fig. 201). Although this pollen is lost to the plant, that which adheres to other parts of the body may be rubbed off on the stigmas of other flowers. The snapdragon, violet, sweet pea, and sage are flowers especially adapted for pollination

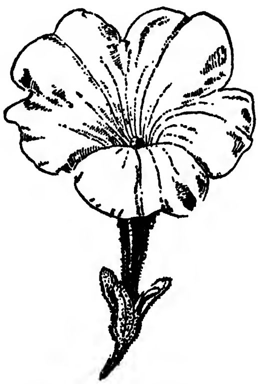


FIG. 200.—Flower of *Petunia*, a type adapted to pollination by moths. Nectar collects at the bottom of the tubular corolla.

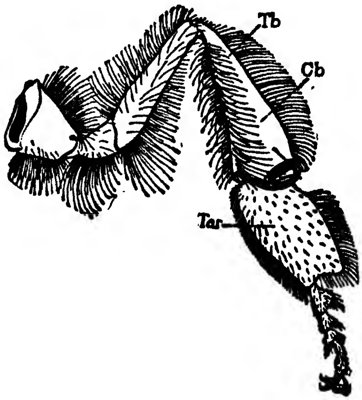


FIG. 201.—Left hind leg of honeybee (worker), showing pollen basket (*Cb*) on outer surface of tibia (*Tb*). (*From Snodgrass, "Anatomy of the Honeybee."*)

by bees (Fig. 202). Although these flowers are not related—belonging to different families, in fact—they have a highly specialized corolla somewhat similarly modified. Normally the flower is more or less closed, the parts of the corolla fitting together in such a way that the stamens and pistil are hidden. The closure of the corolla makes the essential organs inaccessible to ants, which often steal pollen but are practically of no value as pollinators. In all the flowers mentioned above there is a sort of lower lip or platform upon which a bee may alight, the weight of its body causing the corolla to open. The pistil is so situated that, as the bee enters the flower, it comes in immediate contact with the stigma, thus rubbing off some of the pollen brought from another flower. It then encounters the stamens, usually

located below the pistil, and thereby acquires a new lot of pollen. Finally it gathers the nectar and departs.

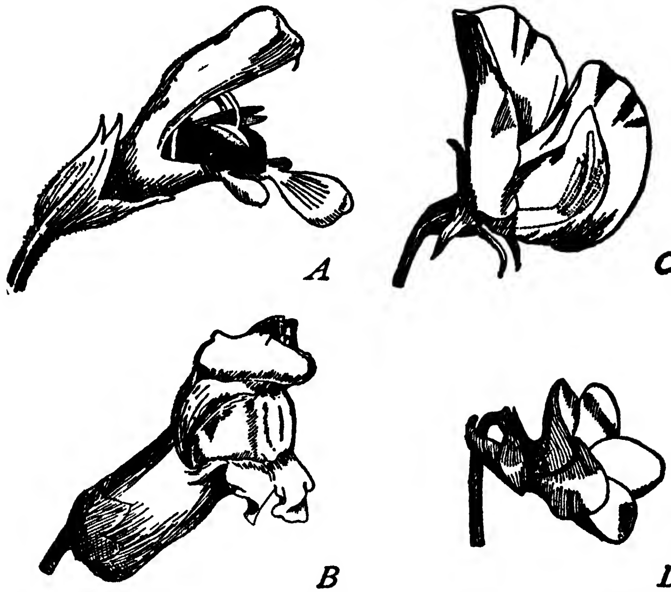


FIG. 202.—Flowers pollinated by bees. *A*, common sage, showing bee entering corolla; *B*, snapdragon; *C*, sweet pea; *D*, violet. In *C* the right lateral petal has been removed. (*A*, *redrawn after Avebury*.)

Protective Resemblance.—In a great many animals the color or form of the body harmonizes with the surroundings, thus rendering it inconspicuous and affording concealment from enemies. A great many examples could be given, but a few will suffice to point out the general situation (Fig. 203). The green body of the katydid with its veined wings blends with the foliage upon which it feeds. The walking-stick insect with its slender elongated body and legs shows a striking resemblance to a branched twig, and thus is very difficult to see. The measuring worms, which are caterpillars of certain moths, are greatly like twigs in form and color, and when disturbed some of them assume a rigid position at an acute angle from the stem. The dead-leaf butterfly (*Kallima*) of India is one of the most amazing instances of protective resemblance known. When its wings are folded, it exhibits almost perfect similarity to an attached dead leaf, in regard to the shape, color, veining, petiole, and even the worm-

holes (Fig. 204). When the wings are outspread, their upper surfaces are seen to be brightly colored.

Fig. 203.—Protective resemblance among insects. *A*, katydid; *B*, walking-stick insect on a twig; *C*, larva of geometrid moth resting extended from a twig. (*A, from Riley; B and C, from Jordan and Kellogg, "Evolution and Animal Life," D. Appleton-Century Company, Inc., New York, by permission.*)

The color change of the chameleon and certain other lizards from brown to green, or *vice versa*, to harmonize with the background is well known. A protective coloration of mammals in the wild state is very common. Prairie and desert forms, such as the

wolf, camel, and lion, tend to be brown or gray. Arctic animals are usually white, at least during the winter, the polar bear, Arctic fox, and weasel being good examples. Forest-dwelling types, such as the zebra, tiger, and leopard tend to be spotted, striped, or mottled. Some of these forms are colored not so much for protection but to render them inconspicuous to animals upon

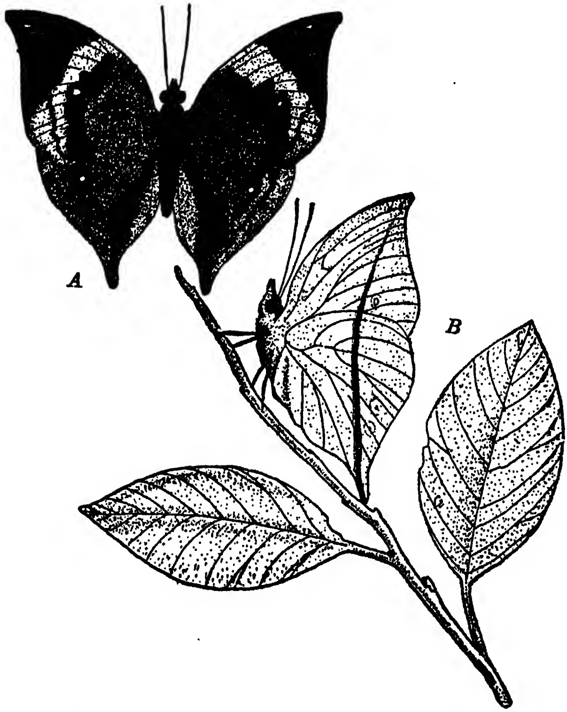


Fig. 204.—The dead-leaf butterfly (*Kallima*) of India, one-half natural size. *A*, with wings extended; *B*, at rest on a leafy twig.

which they feed, while in others, as in many similar cases, the protective value of their coloration has been greatly overrated.

Feet and Bills of Birds.—One of the most striking illustrations of adaptations in animals is seen in the modification of the feet and bills of birds for the performance of diverse functions. A generalized bird, an excellent example of which is the crow (Fig. 205), uses its bill for many different purposes. It can capture insects, pick fruit, dig corn, crack nuts, kill smaller birds, and break open eggs. As a consequence of this varied diet, the bill

of the crow is in no way modified. Similarly its feet are generalized, being used for walking, scratching, perching, wading, walking on snow, etc. The more restricted a bird's diet and the more specialized its method of getting food, the greater is the amount of structural modification that it exhibits. A few examples will be given.

Scratching birds, such as chickens, turkeys, quail, grouse, etc., have short legs and straight, stout, short toes (Fig. 206*A*). They feed mostly on seeds, in consequence of which their bills are short, stout, and curved. Spending most of their time on the

FIG. 205.—Crow (*Corvus brachyrhynchos*), a generalized bird, × ⅙

ground, scratching birds are in general poor fliers. Hawks, eagles, and other *birds of prey* have powerful feet provided with sharp curved claws adapted to seize and carry living prey, and strong hooked beaks for tearing flesh (Fig. 206*B*).

Insect-eating birds are of several different types, some being more highly specialized than others. The woodpeckers dig into tree trunks for grubs and beetles (Fig. 206*C*). Their bills are straight, strong, and chisel-like, the tongue sharp pointed and barbed. The feet are sharp clawed and the tail feathers stiff, the latter acting as a brace against the tree. The nighthawks and whippoorwills are night feeders that capture insects on the wing (Fig. 206*D*). They have long narrow wings and very poorly developed feet. The latter are too weak to be used in walking or even to support the body but are used merely for clinging, the body resting lengthwise on a limb or on the ground. These birds have very small bills surrounded by bristles. They

fly through the air with the mouth widely open swallowing such insects as happen to be in the way.

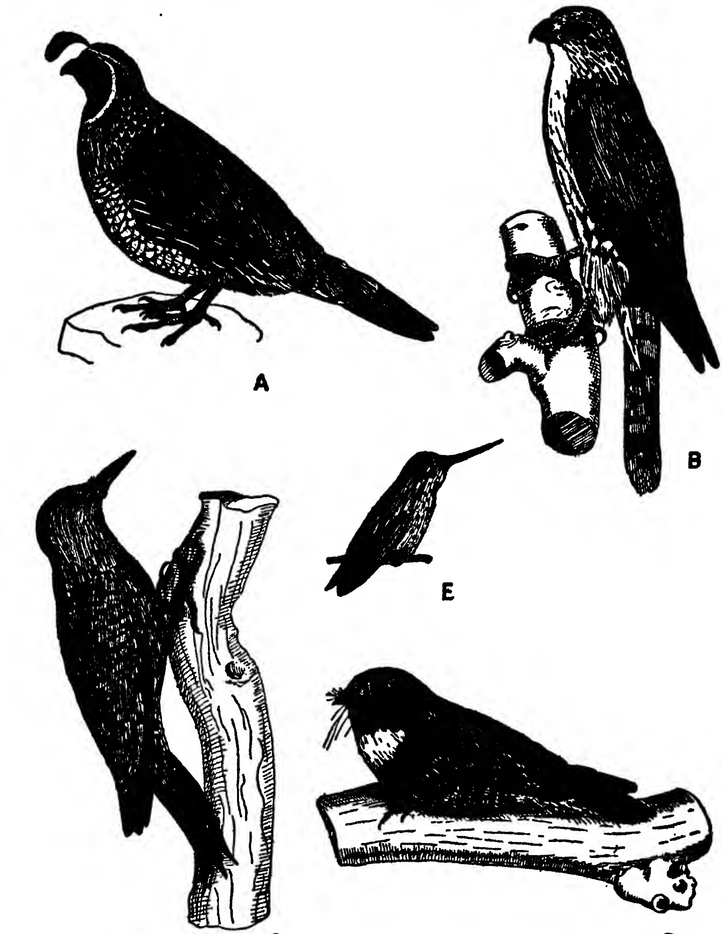


Fig. 206.—Five types of land birds showing adaptation of feet and bills to diverse life habits. *A*, California quail (*Lophortyx californica*), a scratching bird, × ⅕; *B*, pigeon hawk (*Falco columbarius*), a bird of prey, × ⅕; *C*, red-shafted flicker (*Colaptes cafer*), a woodpecker, × ⅙; *D*, poorwill (*Phalaenoptilus nuttalli*), a night-flying insectivorous bird, × ⅕; *E*, hummingbird (*Calypte anna*), a nectar feeder, × ⅓.

The hummingbirds are *nectar feeders*, their long slender bills being well fitted for probing into flowers (Fig. 206*E*). They are the smallest of birds, their rapidly moving wings holding the body poised in front of the flower without coming to rest.

Wading birds are characterized by long slender legs (Fig. 207*A*). The toes are either very long and thin, or shorter and more or less webbed, in either case preventing the bird from sinking into

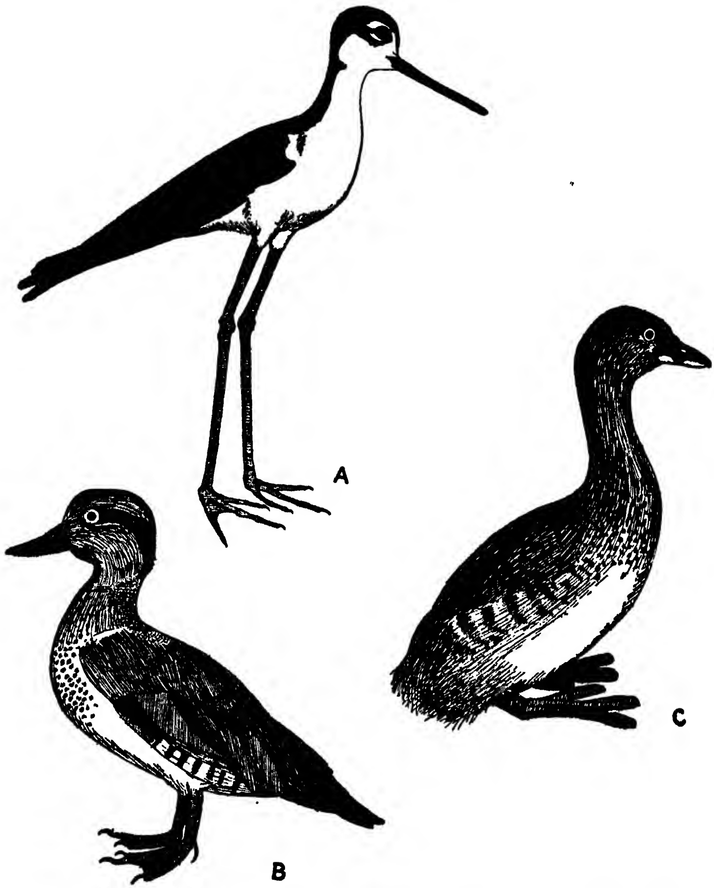


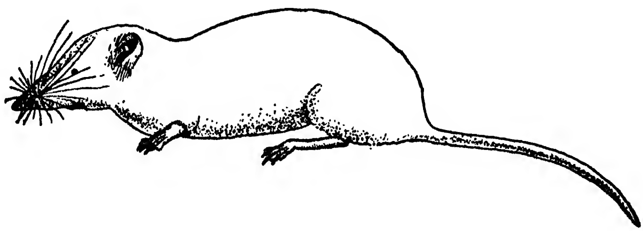
FIG. 207.—Water birds of three different types. *A*, black-necked stilt (*Himantopus mexicanus*), a wading bird, × 1/5; *B*, green-winged teal (*Nettion carolinense*), a swimming bird of the duck type, × 1/5; *C*, pied-billed grebe (*Podilymbus podiceps*), a diving bird, × 1/5.

the mud. Because the legs lift the body above the water, the neck and bill are elongated to permit feeding in the water or in the mud on the bottom. The cranes and herons have long, stout, sharp-pointed beaks for spearing fish, while in the stilts, snipes, sandpipers, and plovers the bill is long but slender and

more or less soft at the tip, being used to probe for small worms, mollusks, crustaceans, etc. along shore or in shallow water.

Swimming birds have lobed or webbed feet, short legs, and are usually awkward on land (Fig. 207*B*). Their bills are modified in accordance with their feeding habits, being pouched in the pelicans, strong and hooked in the gulls, broad and flat in the ducks and geese, etc. Grebes and loons are *diving birds*, swimming under water both to capture fishes and to avoid their enemies (Fig. 207*C*). The toes are webbed or lobed, and the feet placed far back on the body, so that on land an erect position is assumed. The sharp-pointed beak is well fitted for grasping fishes.

Generalized Mammals.—In mammals, as in all other animal groups, a striking correlation between structure and life habits is seen. Although structural modification may affect any part of



the mammalian body, it is particularly evident in teeth and limbs. The most generalized mammals are nearly all ground dwellers, having relatively short, pentadactyl limbs, and walking with the entire foot resting flat upon the ground, a type of progression known as *plantigrade*. Among the most primitive of placental mammals are the shrews—small, mostly terrestrial forms with pointed heads, small eyes, and a general mouse-like appearance (Fig. 208). Shrews live chiefly on insects, their teeth being small, sharp-pointed, and but slightly differentiated.

Teeth of Mammals.—In typical mammals there are four distinct kinds of teeth: *incisors*, *canines*, *premolars*, and *molars*. These can be studied to good advantage in man or in any of the monkeys, where all four types are present in a relatively unspecialized condition (Fig. 209). The primitive number of teeth in mammals is 44, there being in each jaw 6 incisors, 2 canines, 8 premolars, and 6 molars. In most cases, however, this number has been reduced. For example, a dog has 42 teeth, two of the

upper molars being absent. In man 32 teeth are present, there being in each jaw 4 incisors, 2 canines, 4 premolars, and 6 molars.

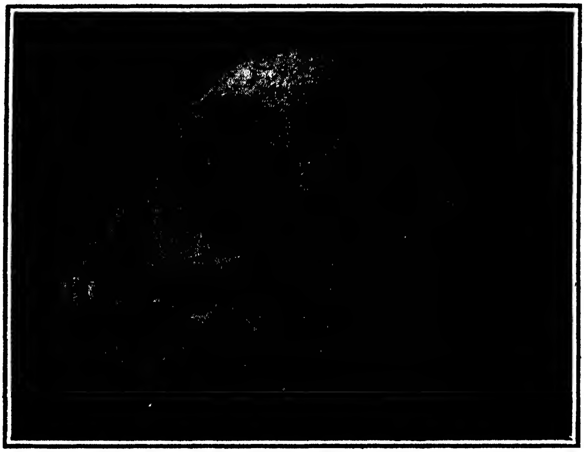


FIG. 209.—Skull of spider monkey (*Ateles*), a mammal whose teeth are relatively unspecialized, × ½. Three pairs of premolars are present in each jaw, but the number of other teeth is the same as in man, making a total of 36.

FIG. 210.—Skull of beaver (*Castor canadensis*), a rodent, × ½. The two pairs of incisors, adapted for gnawing, are large and chisel-like, canines are absent, while the premolars and molars are flat-crowned and adapted for grinding. The total number of teeth is 20.

A tendency in man to reduce the number still further is seen in the late appearance and often imperfect development of the third molars ("wisdom teeth").

In the *rodents*, a herbivorous group including the rats, mice, guinea pigs, squirrels, rabbits, beavers, gophers, etc., the teeth

are adapted for gnawing, and the total number, in many cases, is only 16. The incisors, of which 4 are usually present, are very large and chisel-like, while the 12 molars are flat crowned and used for grinding. No canines are ever present, but some

FIG. 211.—Skull of timber wolf (*Canis occidentalis*), a carnivore, × ¼. The teeth are adapted for cutting and tearing flesh. The total number is 42.

FIG. 212.—Skull of horse (*Equus caballus*), an ungulate, × ⅐. The incisors are adapted for cropping, the premolars and molars for grinding. Small canine teeth are present in the male, but absent in the female. The total number of teeth is 40.

rodents have 4 or even 6 premolars, making a total of 20 or 22 teeth (Fig. 210). The teeth of hares and rabbits are more numerous (totalling 28) and less highly specialized than those of other rodents.

The *carnivores* include the wolves, foxes, cats, bears, raccoons, skunks, badgers, etc. In most cases the teeth are adapted for tearing and cutting flesh (Fig. 211). The cats have the lowest

number (30) and the most highly specialized teeth of this type, the bears (with 42 teeth) the least specialized. The incisors are small and of little use, the canines are large and pointed, while the premolars and molars are sharply ridged.

The dentition of the *ungulates,* or hoofed mammals, in most cases is highly specialized for a herbivorous diet. To this group belong the cattle, sheep, goats, deer, hogs, horses, etc. Hogs have the complete set of 44 teeth, the primitive number. Horses have 40 teeth, there being only 6 premolars in each jaw (Fig. 212). In most of the other ungulates all four kinds of teeth are present, but the total number is still further reduced. The incisors, which are used for cropping grass or herbage, are generally large and chisel-like, while the molars and premolars are broad and flat and provided with a complex surface for grinding. The cattle, sheep, and other ruminants generally have 32 or 34 teeth; there are no upper incisors, the lower incisors biting against a horny pad. Here also the upper canines are usually absent, while the number of premolars in each jaw has been reduced to 6, as in horses.

One order of mammals, the *edentates,* is characterized by an imperfect development or total absence of teeth. To this group belong the sloths, armadillos, and most of the anteaters. A total absence of teeth is also characteristic of some of the whales.

Limbs of Mammals.—It will be recalled that, in a typical vertebrate, the fore limb consists of an upper arm, forearm, wrist, and hand—the hind limb of a thigh, shank, ankle, and foot. In both cases the primitive number of digits is five, the limb thus being *pentadactyl.* In a typical mammal the upper arm consists of a single bone, the *humerus,* and the forearm of two bones, the *radius* and *ulna.* The wrist is made up of a number of small bones called *carpals.* These are followed by the five *metacarpals,* forming the palm of the hand, and the five sets of *phalanges* or finger bones. The corresponding bones in the hind limb are the *femur,* forming the thigh, and the *tibia* and *fibula,* forming the shank. The ankle consists of a number of small *tarsals,* and the foot of five *metatarsals,* which form the sole, and five sets of *phalanges* or toe bones.

Although the fore and hind limbs of mammals are constructed according to the general plan described above, in most groups differences in detail have arisen in accordance with diverse func-

tions (Figs. 213 and 214). Specialization of the limbs of mammals has involved changes in the form and relative length of the bones, a reduction in their number, and often some degree of fusion between certain bones.

There are five chief classes of functions for which mammalian limbs, in different cases, have become modified. These are: (1)

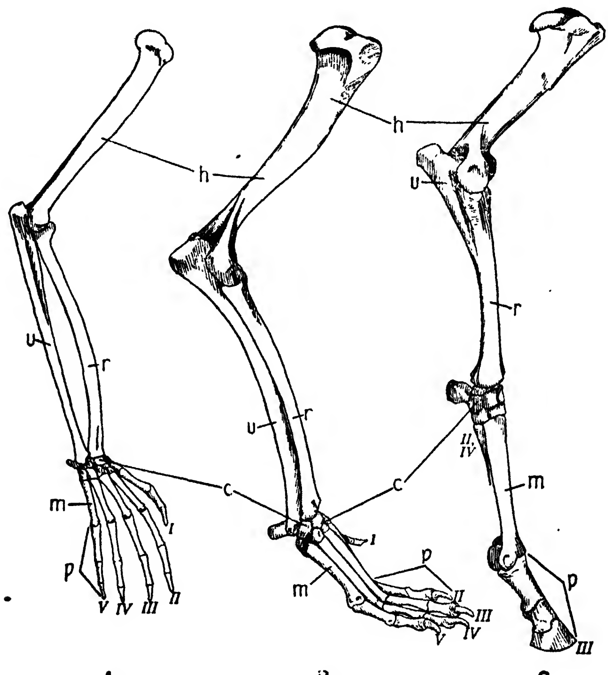


FIG. 213.—Right fore limbs of rhesus monkey, *A*; wolf, *B*; and horse, *C*; *h*, humerus; *r*, radius; *u*, ulna; *c*, carpals; *m*, metacarpals; *p*, phalanges; *I* to *V*, digits. The phalanges are the individual bones comprising the digits.

fossorial, for digging and burrowing; (2) *cursorial,* for rapid running on the ground; (3) *arboreal,* for living in trees: (4) *natatorial,* for swimming; (5) *volant,* for flying. We shall now consider specific instances of each type of functional adaptation.

Fossorial Adaptation.—A number of mammals, especially many of the rodents, excavate burrows and live in them but in most cases they spend much of their time at the surface. The moles, however, live entirely underground, and consequently are very highly specialized for a fossorial existence (Figs. 214*B* and 215).

The spindle-shaped body with its pointed snout, short neck, narrow shoulders, and short tail is obviously adaptive. The extremely short limbs are modified for digging, the hands and feet being provided with long strong claws. External ears are

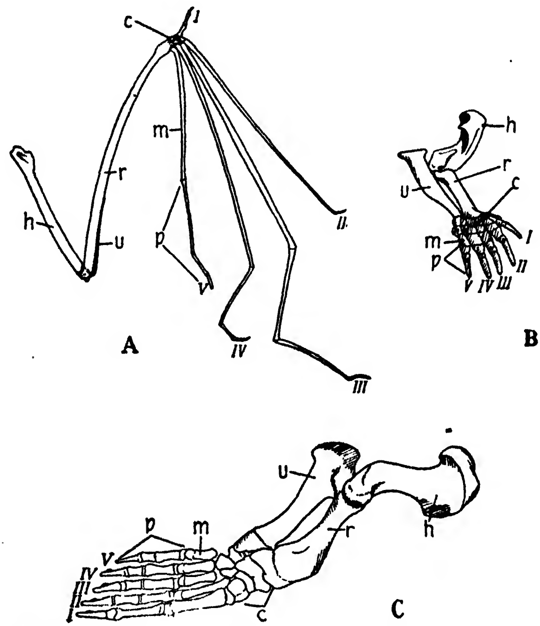


FIG. 214.—Right fore limbs of mastiff bat, *A*; mole, *B*; and harbor seal, *C*. Labeling as in Fig. 213.

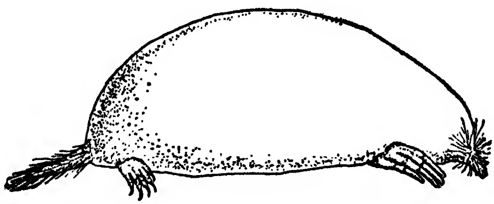


FIG. 215.—A mole (*Scapanus latimanus*), a fossorial mammal, × ½.

absent, and the eyes are vestigial. Moles are *insectivores*, belonging to the same order of mammals as the shrews and hedgehogs. Their teeth are simple.

Cursorial Adaptation.—In mammals that are adapted to run rapidly over the ground, the body is relatively light and the limbs long and slender. The wolves and foxes have limbs pro-

vided with four or five clawed digits. Elongation of the arms and legs has been brought about by an elevation of the wrist and heel above the ground, so that these animals walk on their toes (Fig. 213*B*). This method of progression is designated *digitigrade*. In most ungulates, on the other hand, the digits have been reduced to either three, two, or one, the others being functionless or entirely absent. Ungulates typically walk on the tips of their toes, the hoof corresponding to the nail or claw of other mammals (Fig. 213*C*). Animals that walk in this manner are said to be *unguligrade*. Horses and deer are good examples of unguligrade runners. In many cursorial mammals the radius and ulna are fused together, as well as the tibia and fibula. This prevents a rotation of the limb but enables it to move very effectively in one plane.

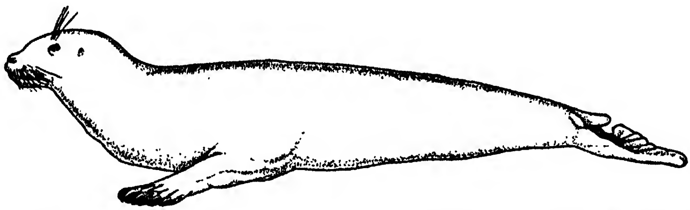


FIG. 216.—Harbor seal (*Phoca vitulina*), a mammal illustrating natatorial adaptation, × 1/10.

Arboreal Adaptation.—The monkeys represent a type of mammal adapted to living in trees. Both the fore and hind limbs are modified for grasping branches, the first digit being opposable to the others (Fig. 213*A*). The tail is long, and in the New World monkeys, is prehensile, thus being of great utility to the animal as it swings from branch to branch. Together with the apes and man, the monkeys form a group of their own, the *primates*. Even the few ground-dwelling primates show many anatomical evidences, especially in the embryo, of a former arboreal existence. Other arboreal mammals are the squirrels and the sloths, the former running along branches, and the latter suspending themselves beneath them.

Natatorial Adaptation.—The seals are aquatic mammals belonging to the carnivore group (Figs. 214*C* and 216). They are not so highly specialized for natatorial existence as the whales and their relatives (*cetaceans*) or as the manatees and dugongs (*sirenians*). The elongated, short-necked, somewhat fish-like

body of the seal with its smooth fur is obviously adapted to progression through the water. The limbs are paddle-like, the upper portion being short, but the hands and feet are elongated and provided with completely webbed digits. The related sea lions and walruses can use their hind limbs in walking, but the seals cannot, thus being more highly adapted to aquatic life.

Volant Adaptation.—Although some mammals, such as the flying squirrels, are adapted for gliding through the air for short distances, the only mammals that really fly are the bats (Figs. 214*A* and 217). To serve this function their bodies are highly modified. The forearm and four of the digits are greatly elongated; these support a thin fold of skin that reaches to the body and to the hind limbs, forming a wing. The thumb is

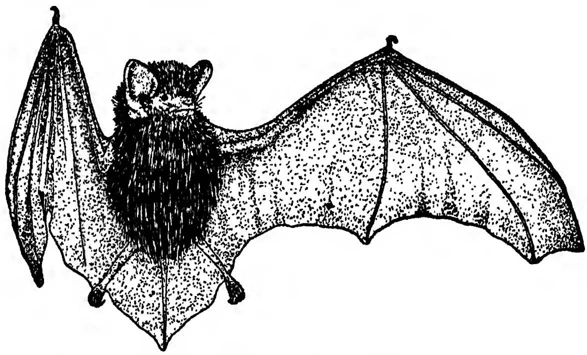


Fig. 217.—Silver-haired bat (*Lasionycteris noctivagans*), a mammal showing volant adaptation, $\times \frac{3}{8}$.

much shorter than the other digits and is clawed. Bats have great difficulty in moving on the ground. When at rest they hang downward from a support by means of their clawed feet, or with head up, suspending themselves by their wing-claws. As in birds the bones are light and the pectoral muscles highly developed.

Adaptive Radiation.—The feet and bills of birds, the teeth of mammals, and the limbs of mammals furnish excellent examples of the *law of adaptive radiation,* which is "the development of widely divergent forms in animals ancestrally of the same stock or of related stocks, as a result of bodily adaptation to widely different environments" (Osborn). Originally all the members of each group were primitive, generalized forms living under the same conditions, restricted in distribution, with similar life

habits, and hence structurally much alike. As migrations into different habitats took place, new conditions were encountered, and structural modification followed. Thus all mammals, although fundamentally of similar structure due to descent from a common ancestry, show many differences as a result of adaptation to diverse conditions of living.

Convergent Adaptation.—Although related forms, living under different conditions, tend toward divergence in form, as stated

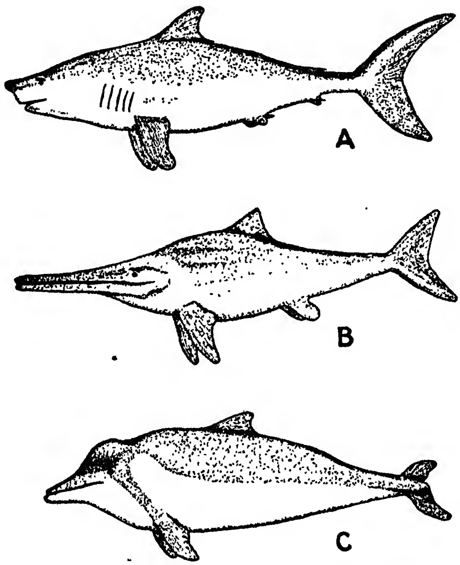


FIG. 218.—Convergent adaptation of form in three wholly unrelated marine vertebrates. *A*, shark (a fish); *B*, an ichthyosaur (an extinct reptile); *C*, a porpoise (a mammal). (*After Osborn.*)

above, unrelated forms, living under similar conditions, tend toward convergence of form. This is the *law of convergent adaptation*, which has been stated as "the production of externally similar forms in adaptation to similar natural forces" (Osborn). Because the conditions for existence in the water require the same sort of adaptive features, we find a marked external resemblance between such wholly unrelated vertebrates as a shark (a fish), an ichthyosaur (an extinct reptile), and a porpoise (a mammal). Each has a spindle-shaped body, paddle-like anterior appendages, a dorsal median fin, and a somewhat similar type of tail (Fig. 218). Fundamentally, of course,

these animals are very different, since they have progressed along independent lines of descent.

The law of convergent adaptation is well illustrated in the case of desert plants. Many species having the same general aspect belong to widely different families, the superficial resemblance being due to their living under the same environmental conditions.

INDIVIDUAL ADAPTATIONS

Although the structure of organisms and the way in which their parts function are determined mainly by heredity, the environment, in providing an opportunity for inherent tendencies to express themselves, constantly exerts a modifying influence. It is apparent that in every habitat conditions constantly fluctuate, and that all organisms, by virtue of the power of irritability, respond to these slight changes, mostly in ways advantageous to themselves. When extraordinary changes occur, however, as when an organism is removed from its natural environment and placed under a new set of conditions, it also may be able to adjust itself, especially if the change is made very gradually.

Adaptive Response.—It is important to distinguish between the state of being adapted and the process of becoming adapted. An organism *is adapted* to the normal conditions of its particular habitat chiefly by reason of its hereditary constitution, and so most adaptive characters are racial. To a limited extent, however, it may react favorably to new conditions that arise; in other words, it may *become adapted* to a new environment. This is known as the power of adaptive response. The reaction to the changed conditions may be functional, structural, or both. Adaptive characters that thus arise as a direct response to external influences are spoken of as *acquired* (or *individual*) *adaptations*. A few examples will be given.

Everyone knows that the growth of a plant is greatly influenced by temperature, light, moisture, character of the soil, diseases, injuries, etc. When a plant is grown in darkness it fails to develop chlorophyll, its leaves remain small, and the stem becomes very long and weak (Fig. 219). Such shoots, arising from seeds deeply buried in the ground, are stimulated to reach up toward the light, where the leaves may enlarge and turn green. There are many other responses in plants where adaptation is clearly indicated. When grown in the shade,

many kinds of plants have larger leaves than when grown in bright sunlight, and so a greater amount of green tissue is exposed for carrying on photosynthesis. Many plants develop more extensive root systems in dry soil than in moist soil, thus enabling sufficient water to be absorbed. The cuticle on many leaves becomes thicker when they are grown under dry conditions, transpiration being thereby diminished. In the water buttercup and mermaid weed, the same plant produces finely dissected leaves beneath the water and entire leaves when

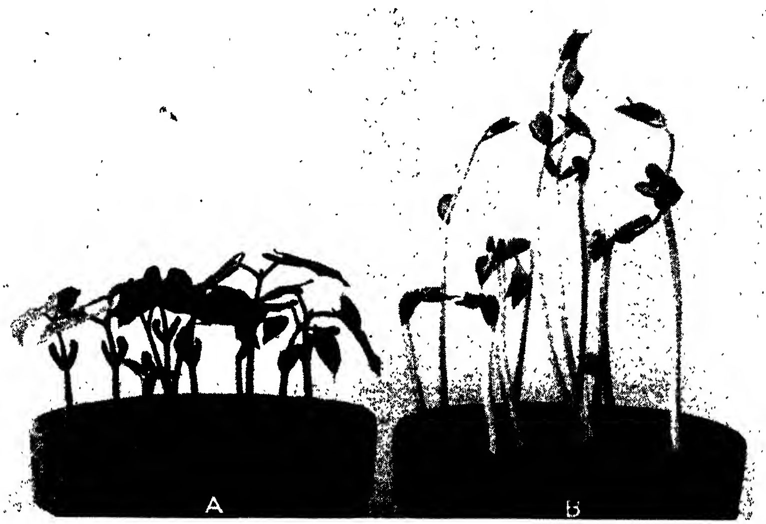


Fig. 219.—Two pots of bean seedlings exactly of the same age. *A*, plants grown in the light; *B*, plants grown in total darkness. In the latter the stems are white and the leaves pale yellow. Both sets of seedlings were given the same amount of water and kept at the same temperature.

it grows up into the air. Such plants exhibit extreme plasticity in their response to external conditions.

Animals are influenced by temperature, moisture, the character and amount of food, exercise, diseases, injuries, etc., and many of the changes thus brought about are adaptive. A familiar example is the tanning of the human skin through continuous exposure to bright sunlight. The formation of brown pigment, which in the negro is racial, tends to prevent further burning and consequent injury to the underlying tissues. The development of callosities on the skin through friction is also an adaptive response, as is the enlargement of muscles by persistent exercise. Recovery from a disease often brings about a condition of immu-

nity to further attacks, and a tolerance for certain poisons, such as caffeine or nicotine, may be gradually acquired.

An important limitation that should be kept in mind regarding the power of adaptive response is that only minor adjustments are possible. The basic features of organisms are incapable of modification. By a manipulation of the environment we cannot increase individual human stature, change eye color, increase potential intellectual ability, or alter any of the other characters that are determined largely by heredity. In the vast majority of cases the amount of modification that may be effected through a radical change in external influences is slight and always limited. The striking cases ordinarily mentioned are exceptional, some organisms being much more plastic than others and hence more susceptible to modification.

Explanation of Adaptation.—In speaking of the power of adaptive response, it is often said that an organism "adapts itself" to this or that condition of the environment. This and all similar phrases implying conscious efforts or purpose should be avoided, as their meaning is entirely metaphorical even in the case of intelligent animals. Some reactions are advantageous, while others are not, but in neither case can desire on the part of the organism produce a modification in structure or function. For example, as waste products of metabolic activity, some plants produce substances that may happen to be bitter, poisonous, or otherwise unattractive to certain animals, and such plants may be avoided for this reason. But to say that they produce substances "to protect themselves" from being eaten by animals is entirely misleading in that it implies foresight on the part of the plant.

If adaptation is not purposive, how has it come about? Like many other biological problems, this is a question that has never been satisfactorily answered. Most individual adaptations are in the nature of direct responses to external conditions, but we cannot explain why an organism reacts to a given stimulus in a characteristic way. Regarding the origin of racial adaptations, it is certain that they have arisen by a process of evolution, but as to how they have evolved there is much uncertainty. Two plausible theories have been suggested: one called *the inheritance of acquired characters*, the other, *natural selection*. These are discussed in their proper setting in Chap. XXII.

CHAPTER XIX

SAPROPHYTISM, PARASITISM, AND SYMBIOSIS

It has been pointed out in the last chapter that organisms are related in their life habits not only to the physical factors of their environment but to other organisms as well. Each kind of living thing has reciprocal relations with other kinds—none can live unto itself. The limitless ways in which organisms are associated and interact with one another constitute such a vast subject, however, that here we can give attention only to a few of its many aspects. The phenomena of saprophytism, parasitism, and symbiosis are of particular interest to the student of general biology because they illustrate some of the more striking ways in which organisms are adapted to the living environment.

SAPROPHYTISM

Saprophytes are plants without chlorophyll that absorb their food directly from dead organic matter. Their supply of carbon comes not from the carbon dioxide of the air, as does that of green plants, but from organic compounds occurring in dead plants and animals or in the waste products of living organisms. In the course of obtaining food for themselves, saprophytes gradually break down these complex organic compounds into simpler products and thus are the direct cause of decay. It is important to realize that the decomposition of all dead organic matter takes place entirely through the agency of living organisms, which thereby obtain material and energy necessary to their own metabolism. Although the breaking down of carbohydrates is called *fermentation,* and the breaking down of protein material, *putrefaction*, these processes are essentially similar.

Decay of Organic Matter.—The decomposition of dead organic matter involves a complicated series of changes, there usually being a large number of intermediate products formed, such as various alcohols, organic acids, etc. Ordinarily there is a succession of various kinds of decay-producing organisms, chiefly

bacteria, each carrying the process a little farther, until finally only a few relatively simple substances are left. All these organisms gain their subsistence from the great amount of potential energy contained in the dead material, but none except the last ones exhausts it. The ultimate products of decomposition are chiefly water (H_2O), carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), hydrogen sulphide (H_2S), free hydrogen, and free nitrogen. The water and carbon dioxide may be directly

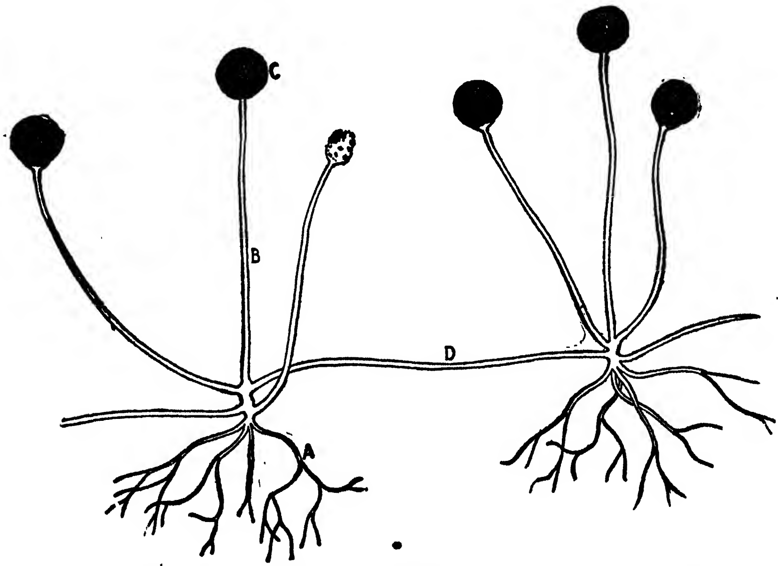


FIG. 220.—Mycelium of bread mold (*Rhizopus*) giving rise to sporangia. *A*, haustorium; *B*, sporangiophore; *C*, sporangium; *D*, horizontal branch. (*From Sinnott, "Botany; Principles and Problems."*)

used again by green plants in the synthesis of new organic compounds, but the other substances can be utilized only after being acted upon by certain other bacteria that oxidize them in order to obtain a source of energy for themselves. For example, ammonia is converted to nitrites and then to nitrates by the *nitrifying bacteria*, of which there are two types, one carrying on the first change, the other the second. Other kinds of bacteria oxidize methane, hydrogen sulphide, and free hydrogen, forming substances directly utilizable by green plants, while still others, the *nitrogen-fixing bacteria*, have the power of forming nitrates directly from free nitrogen (see pp. 332–333 and 359).

Besides the bacteria of decay, many other kinds of saprophytes are found among the fungi, examples being yeasts, molds, mushrooms, and many others. These plants live on humus, rotting logs, dead animals, etc. The yeasts are unicellular, but most of

FIG. 221.—Two saprophytic seed plants found in rich, moist woods. On the left, Indian pipe (*Monotropa uniflora*); on the right, pinesap (*M. hypopitys*). (*Photograph supplied by McFarland Publicity Service.*)

the other fungi have a delicate, white, thread-like body called a *mycelium* (Fig. 220). The fleshy "mushroom" (Fig. 27) is really only a spore-producing structure, the vegetative body of the plant being a mycelium that grows in the soil or in decaying wood. Only a relatively few saprophytes occur among the seed plants, one of the best known being the Indian pipe (*Monotropa*

uniflora, Fig. 221). The whole plant is white or sometimes reddish and is entirely without chlorophyll. The unbranched stem, often reaching a height of a foot, bears a few reduced leaves and a single terminal flower. The Indian pipe grows in rich moist woods, absorbing its nourishment from the partially decayed organic matter contained in the soil.

Cycle of Elements.—By virtue of their ability to construct food from inorganic substances, green plants provide a source of

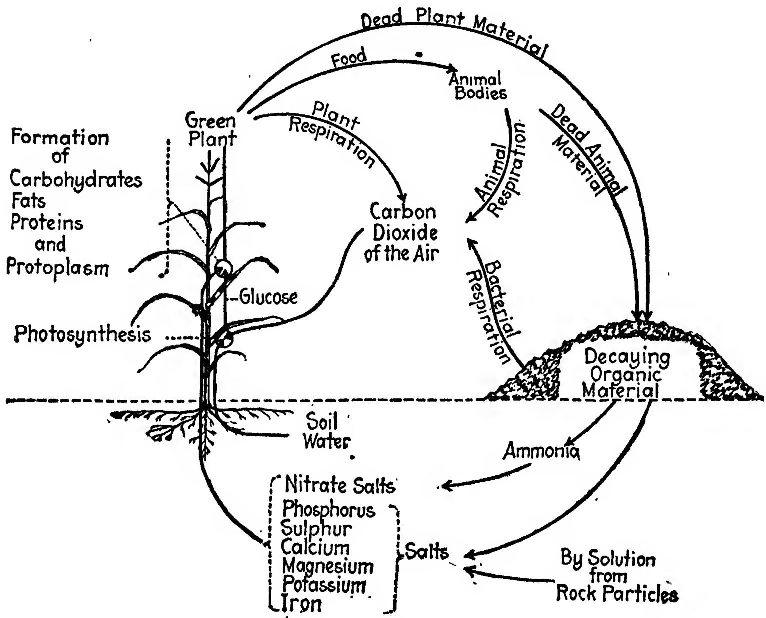


FIG. 222.—Diagram representing the circulation of elements through the air, soil, and bodies of organisms. (*From Sinnott, "Botany; Principles and Problems."*)

material and energy for themselves, for animals, and for dependent plants. It will be recalled that green plants obtain the entire supply of carbon, hydrogen, and oxygen that they use in food manufacture from the carbon dioxide of the air and the water of the soil, and that these elements enter into the formation of all the organic substances in plants and animals. All the other elements that become part of the plant body, however, such as nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron, etc., are absorbed as salts dissolved in the soil water (Fig. 222).

It should be understood that the chemical elements of which the various components of protoplasm and its derivatives are constructed are only temporarily associated in an organism. During life, waste products resulting from the breaking down of organic matter in respiration are constantly given off, while after death destructive processes continue under the influence of other organisms. A plant may be eaten by an animal and some of its substance become temporarily transformed into animal protoplasm, but eventually all organic matter constructed by green plants is decomposed into its constituent elements. It is apparent that saprophytes, in effecting this decomposition, ultimately return elements to the inorganic world. Without them dead plants and animals would rapidly accumulate, and the various elements essential for life would be "locked up" and so rendered unavailable for green plants. Eventually the carbon dioxide of the air and the mineral salts of the soil would become so greatly depleted that life would cease. It is evident, therefore, that saprophytes play a much more important role in the economy of nature than is commonly realized.

Because all the products resulting from the breaking down of protoplasm and its derivatives, both during life and afterward, are either immediately available for use again by green plants or are ultimately rendered so, and because green plants supply all the food that other organisms utilize, there exists in nature a continual circulation of elements—in its complete form, from the inorganic world through green plants to animals, to saprophytes, and then back to the inorganic world. A careful study of Fig. 222 should make this situation clear.

PARASITISM

So far as plants are concerned, there is no sharp line of distinction between saprophytism and parasitism. All dependent plants absorb organic substances from an external source, and it makes little difference whether the source is living or dead. In fact, many fungi may live either as saprophytes or as parasites, that is, are *facultative*, in contrast to the *obligate* forms that can live only one way or the other. Similarly parasitism among animals is not a clearly defined phenomenon. All animals eat either dead or living organisms (or their products), and so have the same relation to their food supply as do dependent

plants. We do not, however, consider the relation between a predatory animal and its victim, or a herbivorous animal and the vegetation upon which it feeds, as cases of parasitism.

Parasitism, as applied to both plants and animals, has a rather limited meaning, being used to describe cases where one kind of organism lives in or on another, obtaining its food at the other's expense. The two organisms involved in this type of association are known respectively as *parasite* and *host*. Not only does the parasite receive all the benefits of the association, but the host is always more or less injured. If injured sufficiently to cause some marked disturbance in its normal functions, the host is said to

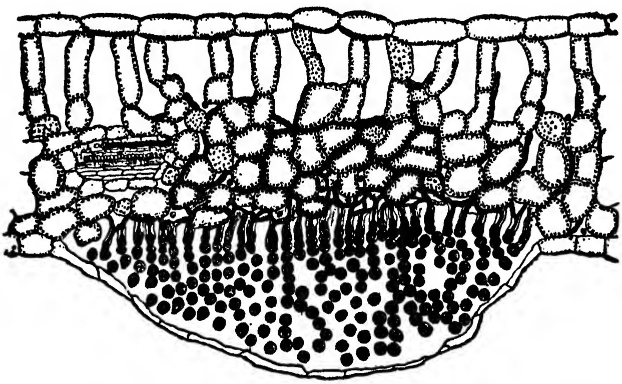


Fig. 223.—Cross section of a radish leaf infected with a parasitic fungus (*Albugo candida*), × 100. The mycelium forces its way between the mesophyll cells and produces spores beneath the epidermis, thus forming a blister on the surface of the leaf, which finally ruptures and liberates the spores into the air.

be diseased. It should be understood that the *disease* is merely a response on the part of an organism to the presence of a parasite living upon it. A disease manifests itself by *symptoms*, which are abnormalities in function or structure caused by the destruction of host tissue, the liberation of poisonous material (*toxins*), or both.

Parasitic Plants.—Among plants by far the greatest number of parasites, as of saprophytes, are found among the bacteria and other fungi, all of which lack chlorophyll and are consequently dependent upon some external source of food. Parasitic bacteria live on both plants and animals, but nearly all the other fungi that are parasitic confine their attacks to plants. Among the many plant diseases caused by fungi other than bacteria, the

following may be mentioned: downy mildew of grape, potato blight, brown rot of stone fruits, corn smut, and wheat rust. Some fungi are external parasites, the mycelium living on the surface of the host and sending short branches (*haustoria*) into the epidermal cells, but in most parasitic fungi the mycelium lives within the tissues of the host and merely produces spores

FIG. 224.—Galls produced on cherry twigs by the "black-knot" fungus (*Plowrightia morbosa*). The gall consists of mycelium and hypertrophied host tissue.

at the surface (Figs. 26 and 223). Some parasitic fungi cause a hypertrophy of the host tissue, resulting in the formation of tumors or galls (Fig. 224).

Of the bacterial diseases of plants, the following are widespread: pear blight, cabbage rot, cucurbit wilt (attacking melons, squashes, and cucumbers), and crown gall. Most of the diseases of man and of the higher animals are caused by bacteria, the following being well-known examples: typhoid fever, tuberculosis, diphtheria, choleria, pneumonia, and tetanus (lockjaw).

Only a few parasites are found among the higher plants, two conspicuous examples being the dodder (*Cuscuta*) and the mistletoes. The dodder, a relative of the morning-glory, attacks various woody and herbaceous seed plants (Fig. 225). The very slender, yellow or orange, practically leafless stem twines about the host and sends short sucker-like processes into it. These penetrate the vascular system, absorbing from it both food and water. Except in the seedling stage, the parasite has no connection with the soil and, lacking chlorophyll almost completely, is unable to carry on photosynthesis.

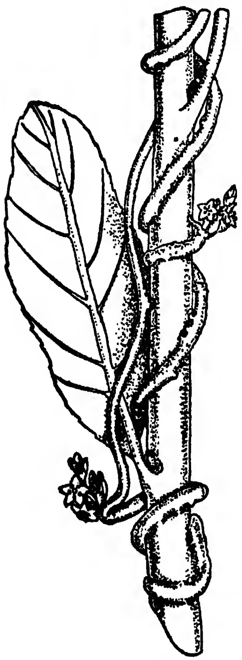


Fig. 225.—Dodder (*Cuscuta*), a seed-plant parasite, twining about a poplar stem, natural size. Short, sucker-like processes are sent into the host, and through them nourishment is absorbed.

Mistletoes live on various kinds of trees. Like the dodder, they send suckers into the vascular tissues of the host (Fig. 226). Although some kinds of mistletoes are entirely parasitic, others are only partially so. The latter have green leaves and are able to make at least part of their own food but, having no connection with the soil, all mistletoes obtain their entire supply of water and mineral salts from the host. The seeds of mistletoes are sticky and are distributed by becoming attached to the feet of birds.

Parasitic Animals.—Animal parasites are found among many different groups, such as protozoans, flatworms, roundworms, annelids, crustaceans, insects, arachnids, mollusks, and vertebrates, but are very rare among the last two. Some animal parasites may be external, such as fleas, lice, bedbugs, mosquitoes, leeches, ticks, etc., and many of these are partial or occasional parasites, since a contact is made with the host only when the parasite is feeding. The most highly specialized parasites are internal ones, such as many protozoan parasites, worms of various kinds, etc. Some are parasitic only during part of their life, others are permanently parasitic and cannot exist apart from

their host. Some can live on a variety of hosts, others only on one kind of host or on a succession of several specific hosts.

FIG. 226.—A mistletoe (*Phoradendron villosum*) growing on an oak tree and (below) a closer view of another species (*P. longispicum*) growing on a poplar stem, one-third natural size.

Correlated with their easy life, many animal parasites, particularly internal ones, are sluggish and structurally degenerate, having lost their organs of special sense, food-getting, locomotion, etc. Such degeneration has come about as a result of the protec-

tion against enemies afforded by parasitism and of the presence of an abundant and accessible food supply. In their larval stages some parasites are free living and are often structurally more complex than when mature. The most highly specialized parasites require two different hosts to complete their life cycle, as the two examples given below illustrate.

Malarial Parasite.—One of the greatest discoveries of modern medicine is that organisms which cause certain human diseases are carried by insects, and this fact has been known in connection with the transmission of malarial fever only since 1898. The parasite that causes malaria in man is a minute protozoan called *Plasmodium,* which goes through a rather complicated life cycle (Fig. 227). The only mode of infection is through the bite of a diseased female mosquito of the genus *Anopheles.* As it enters the human body, the organism consists of a minute, slender, pointed cell that invades and feeds upon one of the red blood corpuscles. As a result, the organism gradually increases in size, coming to resemble a small amoeba. After destroying the contents of the corpuscle, it produces a number of small spores that escape, each entering another corpuscle and repeating the processes of growth and reproduction. When the spores escape, poisons are liberated into the blood stream. These represent waste products resulting from the destruction of the corpuscle as well as those arising from the parasite itself. It is the liberation of this poisonous material that causes the chill and fever characteristic of the disease. In some forms of malaria these symptoms occur at regular intervals, as every 48 or 72 hours, coinciding with the production of spores by the parasite.

If a malarial patient is bitten by an *Anopheles* mosquito, a number of malarial organisms enter the body of the insect with the blood which it sucks. There they undergo a series of complex changes, finally resulting in the production of a great many spores of a different kind. When the infected insect bites another human being, some of these spores are injected into the blood stream, and the individual contracts the disease. It is evident that the only way in which a man can contract malarial fever is through the bite of a mosquito that itself carries the parasite by having bitten either a malarial patient, or a person who has recovered from the disease but still carries some of the parasites in his blood. It has long been realized that the

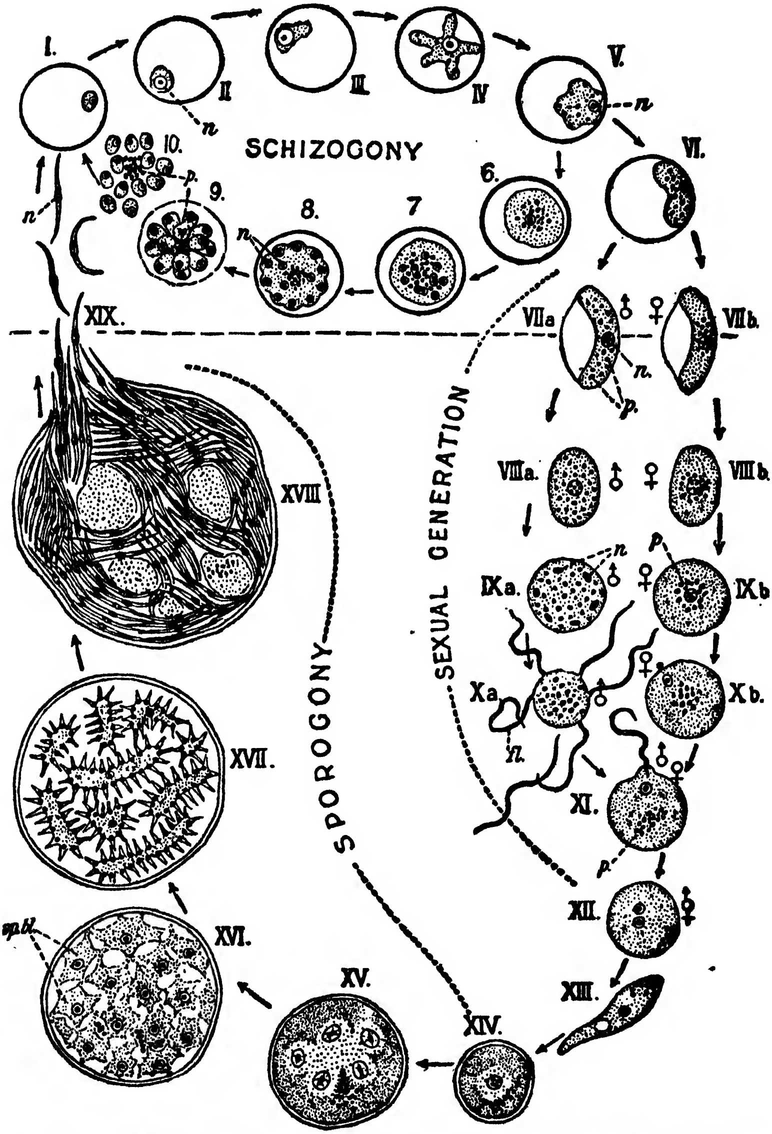


FIG. 227.—Diagram illustrating the life history of the malarial parasite (*Plasmodium malariae*). The stages above the line occur in the human body. Those below in the body of the mosquito. I to V and 6 to 10 show parasite entering human red blood corpuscle, growing, and producing spores. During the sexual phase of the life history, sperms and eggs are differentiated and unite to form a zygote (XII). This encysts in the wall of the mosquito's stomach and undergoes changes that result in the formation of a large number of slender pointed cells (XVIII) that make their way to the salivary glands and are then ready to be injected into a human being. (*From Minchin, in Lankester's "Treatise on Zoology," A. & C. Black, Ltd., by permission.*)

most effective way of controlling malaria is to destroy the mosquitoes that transmit the parasites from one human being to another.

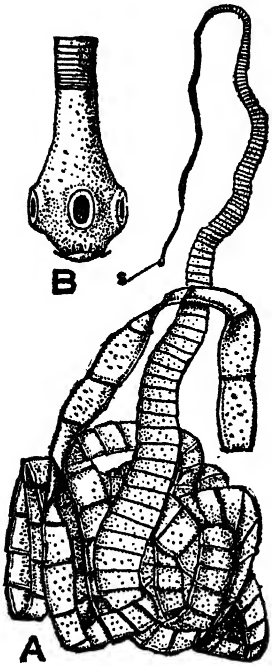


FIG. 228.—The pork tapeworm (*Taenia solium*). *A*, entire worm; *B*, the "head" or scolex (*s*) enlarged, showing adhesive hooks and suckers. (*From Wieman, "General Zoology," after Leuckart-Nitsche wall chart.*)

Tapeworms.—Tapeworms are parasites that live as adults in the digestive tract of the higher animals, there being several species that commonly infect man. Many of them require two hosts in order to complete their life cycle. The body of a human tapeworm is composed of a minute headlike organ (*scolex*) and a number of flat posterior segments (*proglottids*) that become larger and larger throughout its length (Fig. 228). The head is attached to the intestinal wall and gives rise to the posterior segments by a process of budding. Thus the "worm" is really not a single animal composed of a number of metameres, as its general appearance would seem to indicate, but a colony. A single specimen of beef tapeworm (*Taenia saginata*) may consist of several thousand segments and may reach a length of 20 to 30 feet or more. The pork tapeworm (*Taenia solium*) is smaller, rarely exceeding 10 feet in length. Tapeworms have no digestive system; they absorb food through their body wall after it has been digested by the host. Their nervous, excretory, and reproductive systems are essentially similar to those of other flatworms.

The segments pass out of the human body through the digestive tract. Each contains thousands of small embryos, as the tapeworm is hermaphroditic and self-fertilizing. Some of these embryos may then be swallowed by the alternate host, which may be a hog, a cow, or some other animal, depending on the species of tapeworm. After entering the body of the other host, the parasite bores into the muscles, undergoes further development,

and finally becomes encysted. In this form it enters the body of man when infected meat is eaten. The eating of raw or insufficiently cooked pork, beef, or fish is generally responsible for the presence of tapeworms in the human body.

Immunity.—Although a disease is any marked disturbance in the normal functioning of the body, regardless of its cause, an *infectious disease* is one brought about by the entrance of specific microorganisms and their subsequent multiplication within the tissues. Most infectious diseases of man are caused by recognizable bacteria or by analogous organisms (filterable viruses) too small to be seen with the microscope. Some, like malaria, are caused by protozoans.

Disease-producing microorganisms invade the body chiefly through wounds and by way of the respiratory and alimentary tracts. The extent to which the body is harmed depends largely upon the activity of the phagocytes and upon the formation of antibodies. *Phagocytes* are white blood corpuscles that destroy bacteria by engulfing them. They accumulate in large numbers wherever an infection exists. *Antibodies* are substances in the blood plasma that act in antagonism to specific bacteria or to their toxins. Their chemical nature is unknown. Depending upon their action, several different kinds of antibodies are recognized. Thus *antitoxins* neutralize toxins and render them harmless, *lysins* dissolve microorganisms or cause them to disintegrate, *agglutinins* cause them to stick together, while *opsonins* act upon microorganisms in such a way as to render them more easily destroyed by phagocytes.

In certain diseases the toxins arising from the causal organisms stimulate the body to produce more antibodies and thus increase its resistance to them. The ability of the body to resist the effects of invading germs or their toxins is known as *immunity.* Immunity may be either natural or acquired. Some persons are more resistant than others to a given disease, such inherited resistance constituting *natural immunity.* Resistance developed during the lifetime of an individual is known as *acquired immunity.* It may be either active or passive. *Active immunity* is acquired through the production of antibodies by the individual who becomes immune, while *passive immunity* results from the introduction into the body of antibodies produced by another animal.

As is well known, recovery from some diseases produces a lasting immunity from a second attack. Such diseases include smallpox, measles, scarlet fever, chicken pox, mumps, typhoid fever, typhus, plague, cholera, and yellow fever. Recovery from other diseases, such as tuberculosis and malaria, does not confer immunity. Active immunity to certain diseases is not dependent upon infection and subsequent recovery but can be induced by the introduction into the body of preparations containing dead germs, weakened germs, or weakened toxins. Such preparations, called *antigens*, result in the formation of antibodies. For example, active immunity to typhoid fever, lasting from 5 to 8 years, can be secured by injecting into the body a suspension of dead typhoid bacteria. Active immunity to smallpox can be induced by *vaccination*. This is accomplished by rubbing into a scratch made in the skin a preparation containing the living germs (virus) of smallpox after they have been weakened by growth in the body of a calf. The animal contracts the disease ("cowpox") which, when transmitted by vaccination to a human being, results in an extremely mild infection that confers an immunity usually lasting from 7 to 10 years, or even for life.

Passive immunity to diphtheria can be secured by the injection of diphtheria antitoxin contained in the blood serum of a horse that has developed active immunity by repeated doses of diphtheria toxin. This antitoxin gives only temporary immunity and is used chiefly as an aid to recovery after the disease has already been contracted. Although the toxin formed by the diphtheria germs stimulates the body to produce its own antitoxin, the amount is often insufficient to effect a cure unless supplemented by antitoxin from an outside source, as in horse serum. Active immunity against diphtheria is now most commonly obtained by the administration of diphtheria toxoid, a preparation containing the products of growth of the diphtheria germ so modified as not to produce any toxic effects.

In addition to typhoid fever, smallpox, and diphtheria, immunity may be acquired by artificial means in tetanus (lockjaw), rabies (hydrophobia), scarlet fever, cholera, plague, measles, epidemic meningitis, and probably also in whooping cough.

SYMBIOSIS

Symbiosis is an association in which two different kinds of organisms live together to the advantage of one, but in such a

way that the other is not materially injured, or if injured it receives some compensating benefit from the association. Sometimes there is mutual benefit without injury to either. There are many different degrees of mutual dependence, and so a

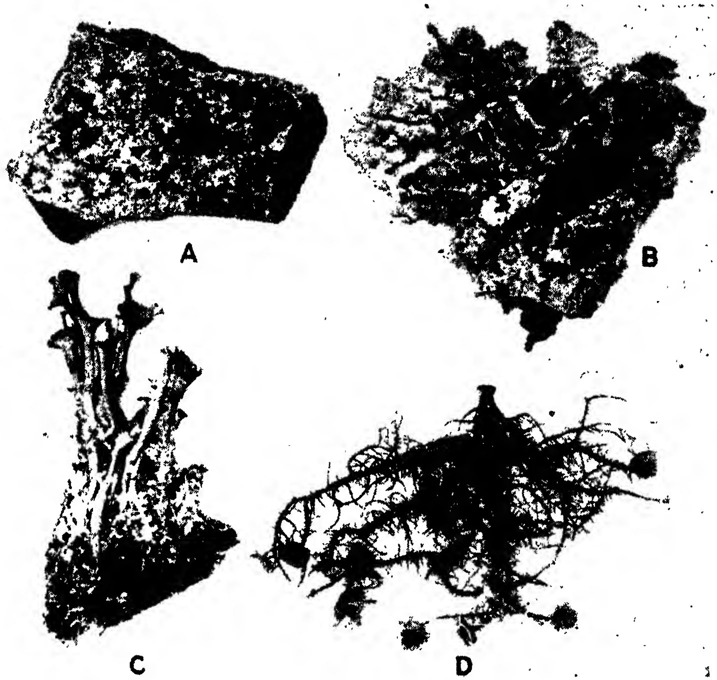


FIG. 229.—Group of common lichens, natural size. *A*, a crustose form (*Placodium*) growing on rock; *B*, a foliose type (*Parmelia*). growing on bark; *C*, a lichen (*Cladonia*) that grows erect upon the ground; *D*, a branching form (*Usnea*) that hangs from the limbs of trees.

number of kinds of symbiosis are often recognized, but here we shall be interested merely in a few well-known examples chosen to illustrate the general situation.

Lichens.—Lichens are small plants of various form commonly seen growing on rocks, tree trunks, dead wood, and on the ground (Fig. 229). Their usual color is gray or grayish green, but some are more conspicuous. A lichen is not a single plant, as its appearance suggests, but an alga and a fungus living together in symbiotic relationship. This is clearly indicated by a cross section through the lichen body (Fig. 230). The greater part of the lichen is composed of a dense mass of tangled fungous

filaments, among which are the cells of the alga either scattered irregularly or in a definite layer. The fungus lives upon the alga as a parasite but does not kill it. In fact, the alga seems to be but slightly injured, merely losing some of the food that it makes. At the same time, however, the alga is benefited in that the fungous body readily absorbs and holds moisture without

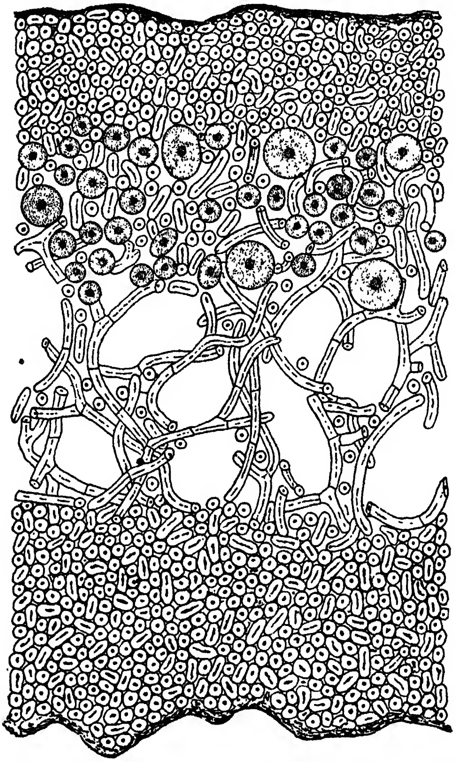


FIG. 230.—Cross section of a lichen body (*Physcia*), showing cells of the alga (above) surrounded by a mass of interlacing fungous filaments, × 500.

which the alga could not live. The alga supplies the fungus with food, while the fungus gives moisture to the alga. This reciprocal relation enables lichens to grow in dry, exposed situations where neither the alga nor the fungus would be able to live alone. Thus the association between the two lichen components is one of mutual advantage.

Nitrogen-fixing Bacteria.—As has been stated, nitrates are formed in the soil both by the action of the nitrifying bacteria

upon ammonia, and by the nitrogen-fixing forms, which convert free nitrogen to nitrates (see p. 318). Although some of the latter are saprophytic upon organic matter in the soil, others enter into a peculiar relation with certain seed plants, particularly legumes, such as clover, alfalfa, beans, peas, lupines, etc. The bacteria invade the roots of the legume and live as parasites upon carbohydrates in the root tissues. As a result of their presence, the roots undergo local enlargement, forming tubercles or nodules (Fig. 231). These bacteria, like the saprophytic forms mentioned above that live free in the soil, are unique in being able to absorb free nitrogen from the air in the soil and to "fix" it, that is, to form nitrogenous compounds within their own cells. After this process has gone on for a while, some of the nitrogenous material becomes available for use by the legume. When the legume dies, a considerable amount of nitrogen is added to the soil, and this is then available for other green plants. As a means of restoring nitrates to impoverished soils, the cultivation of legumes is an important agricultural practice. That legumes have come to depend upon nitrogen-fixing bacteria for their supply of nitrogen is shown by the fact that, when cultivated in sterilized soil, growth is very feeble, even when nitrate salts are present in abundance. For obvious reasons the relation between the nitrogen-fixing bacteria and the legume is often called *reciprocal parasitism.*

FIG. 231.—Root system of a young bean (*Phaseolus*) with numerous tubercles in which nitrogen-fixing bacteria live, one-half natural size.

Ants and Aphids.—The relation that exists between these animals is a sort of slavery and is a real case of symbiosis because both members of the association are benefited. Aphids, or plant lice, are small oval green bugs that suck the juices of plants (Fig. 158*B*). They are often seen on young tender shoots, but some kinds attack roots. Aphids secrete a sweet substance from their bodies called "honeydew," of which ants are very

fond. Wherever aphids are found, ants may be seen running back and forth between the aphids and the ant nests gathering the sweet secretion and carrying it to the larvae. The ants defend the aphids against attack and take care of them in other ways. Some kinds of ants take the aphids to their own nests during the winter and feed them in order to secure a constant supply of honeydew. For this reason aphids are often called "ants' cattle."

Hermit Crabs and Sea Anemones.—Hermit crabs live inside empty snail shells, their cephalothorax, claws, and legs protruding, and the abdomen, which fits inside the shell, becoming soft and devoid of appendages. Some species of hermit crabs place sea anemones on their shell, and thus gain the protection that these creatures, by reason of their numerous stinging cells, afford. The advantage of this association to the anemone is that it is carried about by the crab, and thus taken into new feeding grounds.

CHAPTER XX

THE FACTS OF EVOLUTION

The scientific study of organisms, in all its many aspects, has produced convincing evidence as to the reality of *evolution*—the process whereby modern forms of life have been derived from earlier, simpler forms through the operation of natural laws. All the multitudinous species of plants and animals now inhabiting the earth owe their present condition of structural organization to this process of gradual change; they are the modified descendants of preexisting species.

Geology teaches that the earth, during its formative stages, was lifeless—that primal conditions were not favorable for the existence of organisms. When, where, or how the first life appeared, no one knows. In fact, because of present limitations of our knowledge, the study of evolution is not concerned with the origin of life but only with its development. Its origin is taken for granted. But regardless of how the first living forms arose, all available evidence indicates that they were extremely simple, and that from them have come, by a process of orderly change, forms more and more complex. Life, represented by an unbroken succession of individuals, has been continuous from the beginning, and, since all organisms have had a common origin, all are related by descent.

Two views have been held with respect to the past conditions of organic nature. The older one is that the earth and its inhabitants came into existence in a form like that in which they now exist. It maintains that no changes, except perhaps minor ones, have occurred since life began, and that consequently each kind of organism is fixed and immutable, one species never giving rise to another. Owing to the influence of modern science, this conception of a static world, which has long dominated human thought, has been superseded by the dynamic view, which recognizes the reality of the process of evolution. The latter

is not only supported by a vast array of facts that are without significance on the basis of the former view, which is itself supported by not a single fact, but is actually proved by the historical record of life that has been preserved in the rocks in the form of fossils.

All the physical sciences testify that everywhere in the universe dynamic conditions prevail. Perpetual change is going on everywhere, not only on the earth, but on all heavenly bodies. Permanency in nature is purely a relative term. The physical sciences also demonstrate that the universe is ruled by natural laws, and that, so far as is known, these alone operate in the production of changes. The process of orderly change that characterizes the physical world constitutes what is known as *inorganic evolution.* Recognition of its occurrence is fundamental to the sciences of astronomy, geology, physics, and chemistry. *Organic evolution* is essentially the same process in living things.

No one questions the fact of individual development. The gradual increase in structural complexity as an organism passes from the fertilized egg through successive stages in its growth is self-evident. The fact of racial development, although not nearly so obvious, is just as real. Individual development, called *ontogeny,* is comparatively rapid and of but brief duration, while racial development, or *phylogeny,* has proceeded with extreme slowness over an inconceivably vast extent of time. The hour hand on a clock moves much more slowly than the minute hand, yet moves just as certainly.

From an extremely simple original condition, living forms have, in general, followed a course of changes that has led to ever-increasing complexity of structural organization and specialization of bodily functions. Although evolution has been mainly progressive, in many cases it has operated in the opposite direction and has led to a reduction or loss of parts, or to other degenerative changes. Retrogressive changes, as we have seen, are usually associated with parasitism, but not necessarily so. They are often correlated with progressive changes in another direction. The dulling of the senses of sight, smell, and hearing, which is characteristic of civilized man, has been associated with the development of the brain. Many other examples could be given. However, in any case, whether evolution has been mainly

progressive or retrogressive it is always a process of racial modification.

Importance of Evolution.—The doctrine of descent with modification is a fundamental axiom of biology. As a scientific principle it is as well established as the law of gravitation. The evolutionary interpretation of nature is accepted today by all scientists of recognized standing and has been since the middle of the last century. It is universally accepted because it offers the only rational explanation of a great mass of facts that otherwise would be utterly meaningless. There is no controversy whatsoever among biologists that organisms *have* evolved, although, as will be seen in a subsequent chapter, there is considerable difference of opinion as to *how* they have evolved.

The establishment of the principle of evolution as a fundamental axiom of biology, which represents the greatest intellectual accomplishment of the nineteenth century, probably has had a more profound influence on human thought than has any other scientific generalization. At the present time it dominates all branches of learning, even those having no relation to science. We recognize, for example, an evolution of languages, customs, warfare, government, religious thought, etc. Briefly stated, the establishment of the principle of organic evolution has revolutionized man's conception of the universe and of himself.

Popular Misconceptions.—A great deal of confusion exists in the popular mind concerning evolution; and as a result many false ideas regarding it has become current. One of the most prevalent is that evolution is the subject of a creed—something that one accepts on faith. It should be understood that the principle of evolution, supported by an overwhelming mass of scientific evidence, is a logical explanation of the facts of nature. It is not a theory, although there are many theories relating to how it operates. One does or does not "accept" evolution in the same sense as any other scientific generalization based on demonstrable facts. Moreover, it should be realized that any reluctance one might have in admitting the occurrence of evolution, or of any other natural process, in no way detracts from its reality.

Another misconception is that the knowledge of evolution that one obtains through a study of nature is antagonistic to religion. This is based on a failure to differentiate between the

functions of science and the functions of religion. The distinguished American physicist, Robert A. Millikan[1] says:

> The purpose of science is to develop, without prejudice or preconception of any kind, a knowledge of the facts, the laws, and the processes of nature. The even more important task of religion, on the other hand, is to develop the consciences, the ideals, and the aspirations of mankind.

There can be no real conflict because each properly occupies a different sphere; each appeals to different aspects of human thought. It is only when one takes upon itself the functions of the other that difficulties arise. Science does not deny the existence of a creator; it merely shows that the method of creation is evolution. To say that the world has developed in accordance with natural laws does not deny the existence of an unknown guiding influence, call it what we may.

It is popularly supposed that evolution implies direct descent of man from the gorilla, the chimpanzee, or from some other existing species of ape or monkey. This misconception is based on a failure to understand how the process of evolution has operated. Except in rare instances one form of life cannot be regarded as ancestral to another that is contemporaneous with it.[2] Although all the existing evidence indicates that both man and the apes have evolved from a lower type of life, it also indicates that each has developed independently along a divergent line from some extinct, generalized, common ancestor unlike either living form. Thus the relationship between man and the modern apes is not lineal, but strictly collateral.

Nature of the Evidence.—The principle of organic evolution is an explanation of demonstrable facts drawn from all fields of biological science. These facts cannot be explained on any other basis than that of descent with modification; according to any other interpretation they are rendered wholly unintelligible. Not only do numerous facts of biology support this explanation, but none has ever been discovered that refutes it or warrants

[1] Part of a joint statement issued and signed by a group of 31 leading religious leaders and scientists.

[2] Only a relatively few cases are known where an ancient type of organism has persisted in a comparatively unchanged condition into the present, living contemporaneously with its modified descendants. Nearly all the countless species of plants and animals of the past are utterly extinct.

any alternative explanation. Thus the doctrine of organic evolution stands as a great scientific generalization and is accepted today as such. The evidence upon which the principle rests comprises "the facts of evolution." Some of the more striking classes of these facts we are now ready to consider.

Classification.—We have already seen that all members of the plant and animal kingdoms fall naturally into a number of distinct groups that can be arranged in an ascending series. The major groups are called *phyla*, the more important of which we have already considered in both the plant and animal kingdoms. A phylum may be divided into several *subphyla*, but more commonly directly into *classes*. Thus the vertebrates are a division of the phylum Chordata and consist of five main classes: fishes, amphibians, reptiles, birds, and mammals. Each class consists of smaller groups called *orders*. The carnivores, rodents, ungulates, bats, primates, etc., each constitute an order of mammals. An order is composed of still smaller groups called *families*. The carnivores, for example, include the dog family, the cat family, the bear family, etc. A family, in turn, is an assemblage of related *genera*. Thus the dog family includes the dog genus (*Canis*) and the fox genus (*Vulpes*). Finally each genus includes one or more *species*, and in some species still smaller divisions, called *varieties*, are recognized. The dog genus includes not only the various breeds of the common domestic dog (*Canis familiaris*) but the European wolf (*Canis lupus*), the gray or timber wolf of North America (*Canis occidentalis*), the prairie wolf or coyote (*Canis latrans*), the jackal (*Canis aureus*), etc.

The species is the unit of classification (Fig. 232). It includes individuals that closely resemble one another in form and structure, and although never exactly alike, show less variation among themselves than they do with members of any other similar group. It should be noted that the *scientific name* of an organism is the name of its genus combined with the name of its species. The position of the dog in the animal kingdom is indicated below.

Phylum Chordata (the chordates)
  Subphylum Vertebrata (the vertebrates)
    Class Mammalia (the mammals)
      Order Carnivora (the carnivores)
        Family Canidae (the dog family)
          Genus *Canis* } The common dog
            Species *familiaris* }

can be represented in the form of a tree, signifies that evolution has taken place. In fact, it has no other rational explanation.

Vestigial Structures.—Most plants and animals possess certain parts that perform no useful function and are present in a more

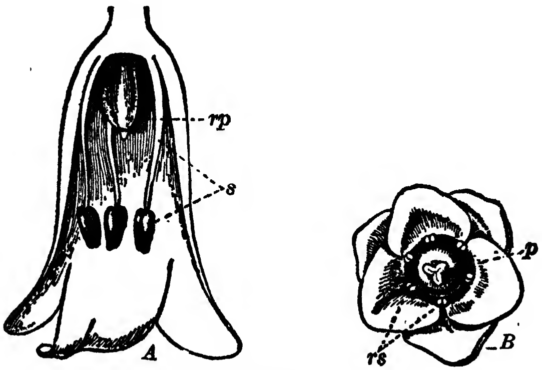


FIG. 233.—Flowers of garden asparagus. *A*, staminate flower, with perfect stamens (*s*) and rudimentary pistil (*rp*); *B*, pistillate flower, with fully developed pistil (*p*) and rudimentary stamens (*rs*). (*From Bergen and Caldwell, "Practical Botany," Ginn and Company, after H. Mueller, by permission.*)

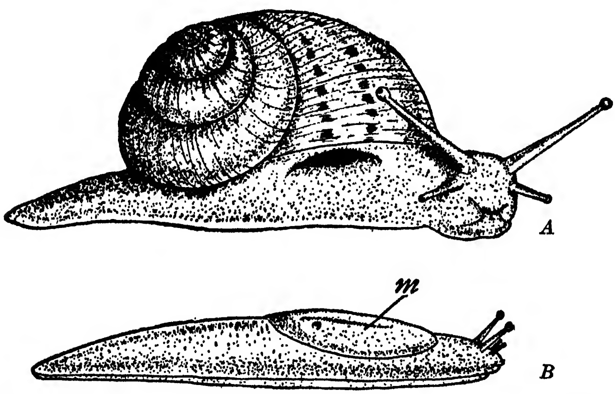


FIG. 234.—*A*, a snail (*Helix*), a mollusk with a well-developed shell, natural size. *B*, a slug (*Ariolimax*), a closely related form, having a vestigial shell covered by the mantle (*m*), natural size.

or less degenerate condition. These are called *vestigial structures.* Their presence can be adequately explained only by assuming that they were more fully developed and functional in the organism's ancestors. A few examples will be given.

The flowers of the common asparagus are of two kinds: one having perfect stamens and a rudimentary pistil, the other with

rudimentary stamens and a perfect pistil (Fig. 233). The only reasonable interpretation that can be placed on this fact is that the ancestors of the asparagus had flowers in which both the stamens and the pistil were functional. The asparagus also has rudimentary leaves in the form of small scales that are entirely functionless. Obviously an adaptation to compensate for the reduced condition of the leaves, and to provide for photosynthesis, is the fact that the stems are green and highly branched, the branches being very fine.

The garden slug is a mollusk closely related to the snails; in fact it is really a snail with a greatly reduced shell. Snails possess a spiral shell into which the soft body can be withdrawn (Fig. 234). The shell is lined with a thin muscular sac called the *mantle*. In the slug the mantle consists of a small oval patch on the animal's back; the shell, of a thin flat plate embedded in the mantle. The presence of this useless shell testifies that the slug has been derived from snail-like ancestors.

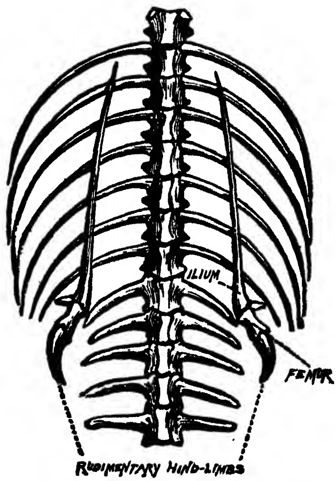


FIG. 235.—Vestigial pelvic girdle and hind limbs of the python, $\times \frac{1}{4}$. (*From Romanes, "Darwin and after Darwin," Open Court Publishing Company, by permission.*)

The snakes and lizards belong to the same group of reptiles, as they have many structural features in common. It is part of their plan of organization to have four limbs, but correlated with the special mode of locomotion assumed by the snakes, limbs are absent. That they have been derived from limbed ancestors, however, is indicated by the presence of vestigial hind limbs in certain existing species of snakes (Fig. 235).

In many of the lower vertebrates there is present a third eyelid (the *nictitating membrane*) consisting of a thin translucent membrane that may be drawn diagonally across the eyeball. In man this structure is represented by a remnant called the *semilunar fold* (or *plica semilunaris*), situated at the inner corner of the eye (Fig. 236). The power of moving the ears so as to catch

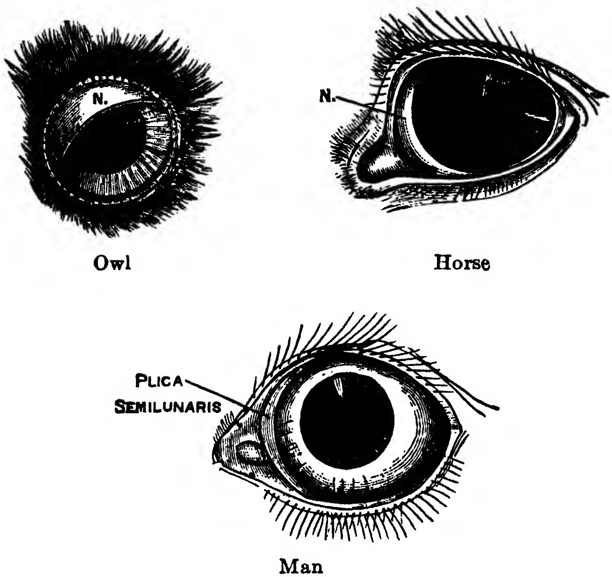


FIG. 236.—The nictitating membrane (*N*) in the owl and horse compared with its rudiment in man. (*From Romanes, "Darwin and after Darwin," Open Court Publishing Company, by permission.*)

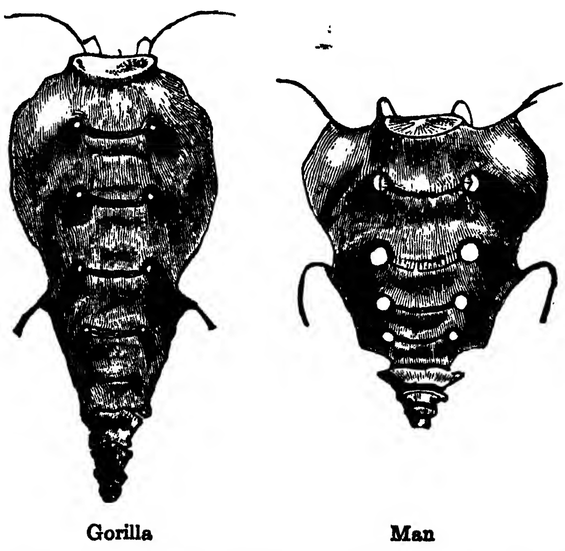


FIG. 237.—Sacrum of gorilla compared with that of man, showing the rudimentary tail bones of each. (*From Romanes, "Darwin and after Darwin," Open Court Publishing Company, by permission.*)

sound more effectively is well developed among such mammals as the dog and horse. In man this power has become lost, but that it was once present is evidenced by the occurrence of feebly developed ear muscles lying close against the head. There are present, at the lower end of the spinal column, a short row of *coccygeal bones,* representing a rudimentary tail that is well developed during a portion of early embryonic life (Fig. 237).

The examples cited above of vestigial structures are only a few selected from thousands that have been described, over a hundred from man alone. They all testify to the reality of evolution.

Embryology.—Attention has been called repeatedly to the fact that every organism which reproduces by the sexual method begins its existence as a single cell—the zygote. It is apparent that this cell represents an individual in the simplest possible condition of structural organization, a condition in which unicellular organisms remain permanently, but multicellular organisms only temporarily. Thus it is a self-evident fact that, like other metazoans, every human being is unicellular at the beginning of its existence.

The series of early embryonic stages involved in the processes of cleavage and gastrulation are essentially alike in practically all multicellular animals (see pp. 233–236). We have seen that some of the lower animals proceed only a short way in their development, some remaining in the blastula stage, others in the gastrula stage. The coelenterates, it will be recalled, are permanent gastrulas, having neither mesoderm nor a coelom. The members of the next group, the flatworms, have mesoderm but no coelom, while all of the higher groups have both features.

In a general way, the sequence of its embryonic stages is indicative of the development through which an animal has gone in the course of its evolution. Embryonic development is a brief and condensed repetition of a series of ancestral stages through which the race has passed. Or, as often stated, *ontogeny* (the development of the individual) recapitulates *phylogeny* (the development of the race). This is a statement of the *principle of recapitulation.* It should not be taken to mean that the parallelism between individual and racial development is perfect, for it is always only approximate.

The recapitulation principle is well illustrated among insects. We have seen that the annelids and arthropods have many struc-

tural features in common and thus are closely related. The life history of any member of one of the higher groups of insects substantiates this interpretation. The larval stage of a butterfly, bee, fly, or beetle is distinctly worm-like, not only in general appearance but in a number of more fundamental respects (Fig. 165). This strongly indicates that the insects have evolved from worm-like ancestors.

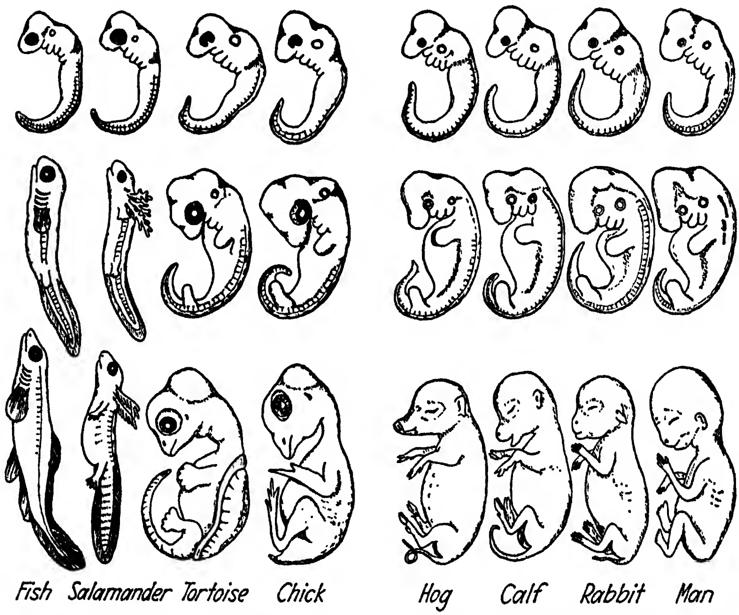


FIG. 238.—A series of vertebrate embryos at three comparable and progressive stages of development. At first all are much alike, but, as development proceeds, differences become more pronounced. Note that the four mammalian embryos, at each stage, resemble one another more than they do any of the other vertebrates. (*After Romanes, "Darwin and after Darwin," Open Court Publishing Company, by permission.*)

Although the earliest stages in embryonic development are essentially similar in all metazoans, it is only among members of the same group that resemblances persist during later development, but these are always striking. For example, in Fig. 238, where embryos representing each of the five great classes of vertebrates are shown, relationship is apparent by their general structural similarity, indicating descent from a common ancestry. This figure also shows that members of different classes begin to manifest conspicuous differences much earlier in development

than members of the same class, denoting descent from an older common stock.

Embryology teaches that many structures which are permanent in the lower members of a group appear only in embryonic stages in the case of the higher members, and then either later disappear completely, persist as vestiges, or become modified to form other structures. For example, during an early period of prenatal development, the human embryo has a tail as well developed as that of any of the other vertebrates (Fig. 238). Likewise, in common with all vertebrates, it has gill slits. The latter become functional only in the fishes and amphibians, as has been seen, but their appearance in all vertebrates is indicative of descent from aquatic ancestors. Moreover, when gill slits are present in the human embryo, the heart is two chambered and the circulatory system distinctly fish-like. The heart then passes through a three-chambered stage, characteristic of amphibians and reptiles, and finally becomes four chambered, as in birds and in other mammals. Similarly the human brain, in its embryonic development, passes through a series of stages corresponding to adult conditions in the lower vertebrate groups.

Intergrading Species.—Before evolution had become an established principle of biology, it was supposed that every species of plant and animal has always existed in its present state, and that each was entirely distinct from all others. It was soon found, however, that, although many species seem to be distinct, some show such a great range of variation that it is very difficult to determine their limits. In other words, some genera exhibit "intergrading species." Typical members of one species may be very different from typical members of another, but often individuals that are intermediate between the two may be found, individuals that show some of the characters of both species. This is true of the asters, roses, hawthorns, willows, oaks, and many other plants. In the animal kingdom, intergrading species are especially common among insects, fishes, birds, and mammals. In all such cases the limits of each species are more or less arbitrarily defined, and taxonomists differ among themselves as to where the lines of demarcation are to be drawn. If all species were fixed and incapable of modification, it would be difficult to account for the occurrence of intermediate forms. But, on the basis of the principle of evolution, genera exhibiting

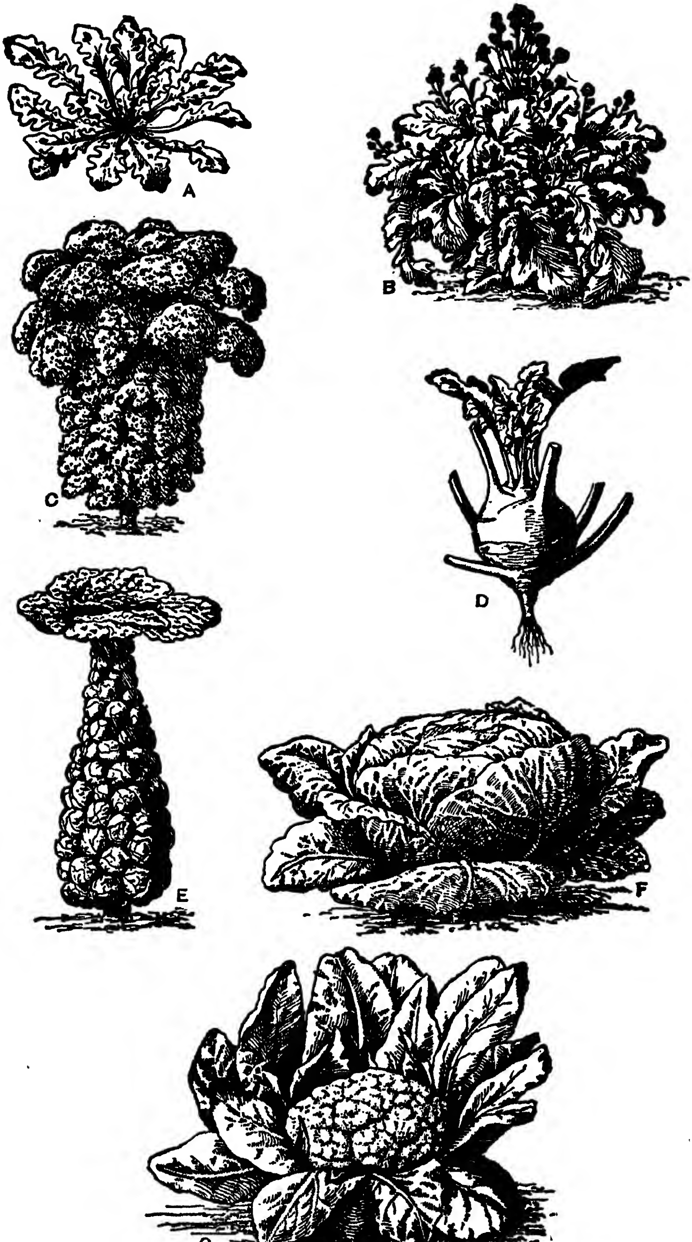


FIG. 239.—Horticultural plants that have arisen from the wild cabbage. *A*, wild cliff-cabbage (*Brassica oleracea*), the probable ancestor of the group; *B*, broccoli; *C*, kale; *D*, kohlrabi; *E*, Brussels sprouts; *F*, cabbage; *G*, cauliflower. (*From Gager, "Fundamentals of Botany," P. Blakiston's Son & Company, by permission.*)

intergrading species may be merely those in an active condition of evolution at the present time.

Cultivation and Domestication.—Everyone is in agreement that all cultivated plants and domesticated animals are the modified descendants of wild species. Many have been under man's influence since prehistoric times, for so long a period, in fact, that their origin is lost in obscurity. In many instances such profound changes have taken place that it is impossible even to recognize the wild ancestral form. Where such recognition is possible, however, striking facts are often revealed. For example, the wild cabbage still grows in Europe but bears little superficial resemblance to its cultivated descendants (Fig. 239). From this single species man has developed not only all the different kinds of cabbages, but also cauliflower, kale, kohlrabi, Brussels sprouts, broccoli, etc. When one considers all the different kinds of pigeons, poultry, cattle, dogs, horses, etc., it is difficult to realize that each group has evolved from one or several original wild species. If species were incapable of modification, such striking changes as these would not have been possible in such a comparatively short time.

Geographical Distribution.—The facts of geographical distribution present additional evidence in support of the principle of evolution. Some plants and animals are cosmopolitan in distribution, but most species are restricted in their natural range to well-defined regions. That peculiarities in distribution cannot be explained on the basis of climatic factors alone is shown by the frequent occurrence of vastly different types of plants and animals in regions widely separated but climatically similar, such as Australia, South America, and Africa.

In general, it has been found that similar but distinct species often occupy adjacent parts of the same region, being kept from intermingling by a barrier of some sort, such as a mountain range, a body of water, a desert, etc. This fact can be satisfactorily explained by assuming that the different species have sprung from a common ancestor that originated in a particular part of the region, or came in from elsewhere, and from this center of dispersal spread as far as conditions permitted. The subsequent establishment of barriers created, by isolation, local groups of individuals that evolved along divergent lines and finally became specifically distinct.

Substantiating this interpretation is the additional fact that the degree of dissimilarity existing between related species separated by a barrier is directly proportional to its geologic age, *i.e.*, to the length of time the barrier has been in existence. Regions recently separated, such as the British Isles and Europe, show great similarity in their fauna and flora, whereas regions long isolated, like Madagascar and Africa, have few forms of life in common.

Special cases of distribution are often interesting. Thus the native mammalian fauna of Australia consists almost exclusively of monotremes and marsupials, groups that in geologic times were widely spread over other continents. These ancient forms survived in Australia, which has been isolated since the close of the Mesozoic era, because there they were kept out of competition with higher types that evolved elsewhere.

The discontinuous distribution of the same group in widely separated regions can be explained on the basis that their distribution was once continuous. This can often be proved by the fossil record. For example, tapirs live only in southern Asia and in Central and South America, but during relatively recent geologic times they ranged over eastern Asia, North America, and Europe as well. Later they became extinct except in the two widely separated regions where we now find them.

The life of oceanic islands is peculiar in that fewer kinds of organisms are present than on continental areas of similar size, that some groups are almost never present, and that a great number of endemic species occur—species found nowhere else. The Galapagos Islands, a volcanic group situated about 600 miles west of Ecuador, has sea birds of the same species as are found on the mainland, but nearly all the species of land birds, reptiles, insects, and snails are endemic. The native fauna contains no amphibians and no mammals except bats. The endemic species, although distinct, show a great general resemblance to South American forms, and so must have been derived from ancestors accidentally brought to the islands from the mainland at rare intervals by wind or waves.

CHAPTER XXI

THE LIFE OF THE PAST

Paleontology deals with the history of life as revealed by a study of fossils—the remains of organisms of the past found embedded in the earth. The "testimony of the rocks" demonstrates the reality of organic evolution in a very striking and direct way. The fossil record proves that a progressive development of plant and animal life has taken place throughout the course of geologic history. As the successive strata that constitute the earth's crust were formed, higher and higher types of life came into being from simpler earlier types by the natural process of evolution. The facts of paleontology, written in the rocks, are a direct record of evolutionary changes.

Nature and Formation of Fossils.—*Fossils* are the remains of plants and animals that once lived upon the earth. Generally they are the hard parts of organisms, for the soft parts nearly always decay or are eaten by animals. The preservation of organic remains occurs under exceptional conditions, and that is why only a relatively few of the countless number of individuals that have lived on the earth have left any trace of their existence. In general, fossils are found in sedimentary rocks and, according to their method of formation, occur as three different types, as follows:

1. *Actual Organic Remains.*—These are simply dead organisms or their parts that have been preserved from decomposition by some special means and consequently have undergone little change. For example, in Siberia and Alaska, the carcasses of mammoths have been found frozen in the soil of the arctic tundras. In some cases the flesh was so well preserved that it could be fed to dogs. Many beautifully preserved insects have been found in amber, a kind of fossil resin. The famous asphalt beds in Los Angeles have yielded the actual bones of many extinct mammals, preserved by the tar into which they fell

(Fig. 240). Actual organic remains are the most favorable fossils for study but unfortunately are very rare.

FIG. 240.—Actual organic remains. Group of bones of the imperial mammoth in an asphalt pit at Rancho La Brea, Los Angeles, California. (*Courtesy of Los Angeles Museum of History, Science, and Art.*)

2. *Petrifications.*—When the organic matter of a dead plant or animal decays but is replaced, particle by particle, by mineral matter dissolved in ground water, a *petrification* is formed. It is chiefly hard parts that have been preserved in this way, such as wood, teeth, bones, shells, etc. (Fig. 241). Petrified fossils show not only external form but often internal structure as well. In such cases thin sections of them can be prepared for microscopic study.

3. *Natural Molds and Casts.*—These are the most common kind of fossils (Figs. 242 and 243). If the body of a dead organism falls

into soft mud or sand, the impression may be preserved after all the organic matter has been destroyed. If the sediment then hardens to form rock, a *natural mold* results. This cavity may later become filled with mineral matter to form a *cast*. It is apparent that molds and casts tell a great deal about the size, shape, and other external features of organisms but give no information concerning their internal structure.

FIG. 241.—Petrified logs, of Triassic age, in the Petrified Forest National Monument, near Holbrook, Arizona.

Division of Geologic Time.—Before considering the history of life as revealed by the fossil record, it will be necessary for the reader to understand how the relative age is determined of the various layers of rock that form the earth's crust. Geology teaches that the surface of the earth is constantly undergoing transformation as the result of the action of various natural forces upon it. One of the most important sets of changes are those involved in the processes of erosion and deposition. The disintegration of rock by weathering and its subsequent transportation, chiefly by running water, result in a gradual wearing down of highlands and a filling in of depressions. According to reliable estimates (F. W. Clarke, 1924), the continents as a whole are being degraded, at the present time, at a rate of 1 foot in

8,600 years. The eroded material, carried to lower levels, is deposited as sand, clay, gravel, etc. Later these sediments may become solidified to form such kinds of rock as sandstone, shale, and conglomerate.

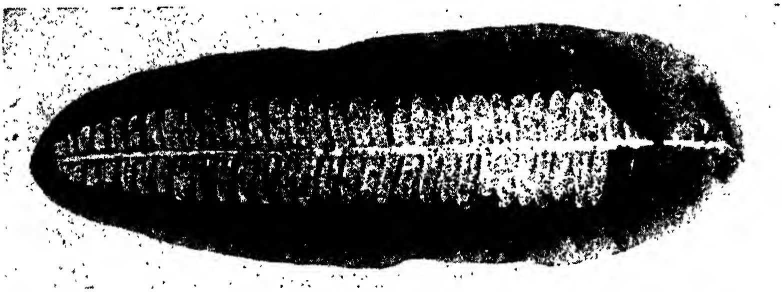


Fig. 242.—An impression in rock of a fern leaf (*Pecopteris miltoni*) from the Upper Carboniferous of Illinois; slightly reduced.

Fig. 243.—Impression in rock of a Miocene fish, natural size.

The processes of erosion and deposition that are going on today in all parts of the world have always been in operation. As a result of continued degradation and slow sinking of the earth's surface, vast portions of what are now dry land have been covered by large bodies of water (Fig. 244). During these periods of subsidence, sedimentary rocks have been formed. Subsequently these areas have been lifted into the air and once

more exposed to the various agents of erosion. Because sediments accumulate very gradually and vertical movements of the earth's surface take place with extreme slowness, enormous stretches of time have elapsed between and during successive periods of deposition.

It is evident that the various strata of sedimentary rocks forming a large part of the earth's crust have been laid down in

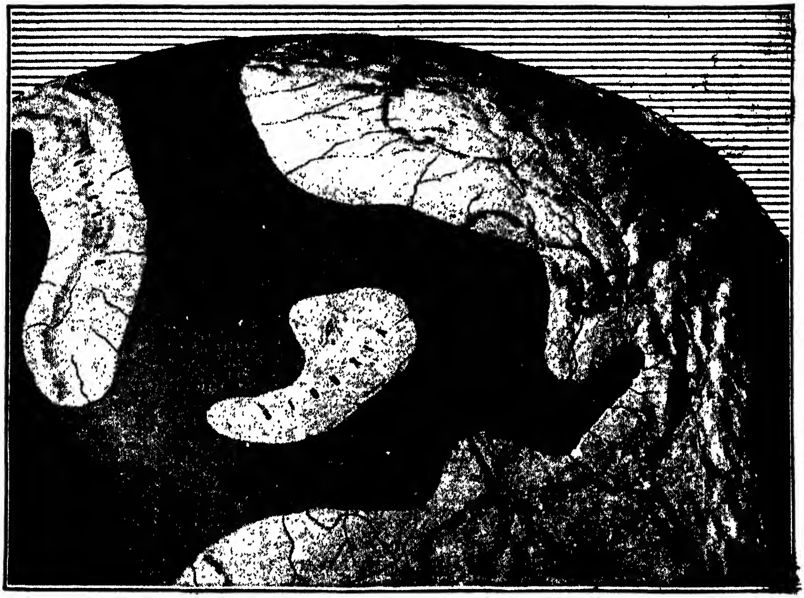


FIG. 244.—Theoretic restoration of the North American continent (white), continental seas (gray), and oceans (black) in Upper Cambrian time, during which there occurred the earliest known great invasion of land by the oceans. The lands were probably all low and the climate warm. (*From Osborn, "Origin and Evolution of Life," Charles Scribner's Sons, by permission.*)

chronological order and, except where disturbed by faulting or folding, the younger rocks lie above the older ones. By studying and comparing the series of stratified rocks in all parts of the world and the succession of fossils that they contain, geologists have been able to reconstruct the history of the earth and its inhabitants in a very definite way. Geologic time is divided into five great *eras*, each era into a number of *periods*, while each period again may be divided into *epochs*. The accompanying table (Fig. 245) gives the names of the geologic eras, their estimated duration, and the characteristic life of each.

Length of Geologic Time.—The geologist deals with time units comparable in their magnitude to the space units employed by the astronomer in measuring the distance between the earth and other heavenly bodies. Because these time units are so stupendous, as compared to the length of a human lifetime, or even to the period of recorded human history (about 5,000 years), they simply stagger the imagination. In fact, at first glance they seem unbelievable.

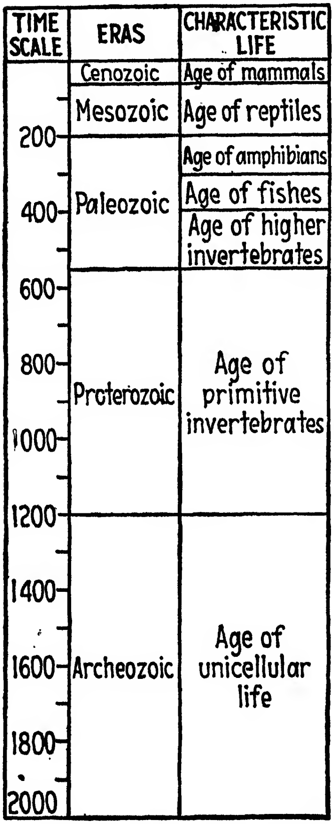


FIG. 245.—Table of geologic eras. The figures in the time scale represent millions of years. These estimates (revised by C. A. Reeds, 1931) are based on the rate of alteration of the radioactive elements.

The geologist has considerable data enabling him to estimate the relative length of the divisions of geologic time, but to assign to each an absolute length is a difficult matter. This arises from the fact that there is no certain way of determining the age of the earth. The older methods, based on the present rate of erosion, or on the rate at which rivers bring salt to the ocean, give about 100 million years as the total elapsed time since the formation of the oldest rocks found in the earth's crust. Because of certain unavoidable errors in the older methods, this figure is now thought to be too low.

More recent calculations, based on the invariable rate of disintegration of the radioactive elements contained in rocks of known relative age, have resulted in a new time scale that is widely accepted by modern geologists and paleontologists as the most satisfactory means devised yet of obtaining an accurate estimate of the total length of geologic time and of its divisions. According to these calculations, the oldest rocks were formed

approximately two billion years ago, and the elapsed time represented by each of the five eras is as follows:

	Million Years
Cenozoic	60
Mesozoic	135
Paleozoic	355
Proterozoic	650
Archeozoic	800
Total	2,000

The life of each of the great geologic eras will now be briefly considered, beginning with the oldest.

THE ARCHEOZOIC AND PROTEROZOIC ERAS

The beginning of life is veiled in mystery, for no one knows when, where, or under what circumstances the first organisms appeared, and no one knows anything about their nature. Presumably they were extremely simple, perhaps more so than any existing organisms. Moreover, no certain knowledge is available concerning the early stages in the development of life on the earth. There is some evidence, mostly indirect, of the existence of life during the Archeozoic, and that by the end of the Proterozoic considerable evolutionary progress had been made, but beyond that, very little is known.

Life of the Archeozoic.—The Archeozoic is the portion of geologic history when the oldest known rocks, comprising the Archean system, were formed. They constitute a complex series of formations underlying all others, and appear at the surface only where uplifted and exposed by erosion. Although mainly igneous in origin, some Archean formations consist of metamorphosed sediments. In fact, all these ancient rocks, subsequent to their formation, have undergone intense alteration through vulcanism and great deformative earth movements. There is no doubt that the duration of the Archeozoic was enormous—800 million years according to reliable estimates. Many geologists think that it was longer than all subsequent time.

Because life is thought to have arisen during some part of this vast era, and to have remained for a long time in a simple form, the Archeozoic is designated as the "Age of Unicellular Life." Striking evidence that life existed in abundance at this time is seen in the vast quantities of carbon that occur throughout the

Archean system in the form of graphite. It seems certain that this carbon must have been derived from the bodies of organisms. The occurrence of limestone is also generally indicative of organic activity. It is thought that the Grenville limestones of eastern Canada, which are many thousands of feet in thickness, may have been formed by the precipitation of lime from sea water through bacterial action.

Being probably of a simple and perishable nature, the earliest organisms were not amenable to preservation, and because of the subsequent alteration of the Archean rocks by great heat and tremendous pressure, whatever direct fossil evidence they might once have contained has been largely obliterated. Recently, however, the occurrence of what seem to be fossil blue-green algae has been reported from Archean rocks of northern Michigan. This discovery is of great interest because the blue-green algae are not only the simplest chlorophyll-bearing plants existing today, but are closely related to bacteria, the simplest of all known forms of life. Many of them live in the waters of hot springs and geysers, enduring high temperatures that would be fatal to other organisms. Thus these algae may have lived on the earth during the Archeozoic, especially if its surface was hotter then than it is now.

Life of the Proterozoic.—In contrast to the predominating igneous rocks of the Archeozoic, the rocks of the Proterozoic are chiefly sedimentary in origin and some of them have undergone extensive metamorphism. Both systems are of immense thickness, bespeaking an enormously-long period of time involved in their formation. Figure 245 shows the estimated duration of the Proterozoic to have been 650 million years, and so it was almost as extensive as the Archeozoic, so far as can be judged.

The Proterozoic has been termed the "Age of Primitive Invertebrates" because the overlying Cambrian rocks contain abundant remains of higher invertebrates that must have undergone their early evolution during the Proterozoic. Animal fossils from Proterozoic strata, however, are both scarce and fragmentary—a few protozoan shells, some sponge spicules, and worm burrows, comprise about the only remains that have been found. Most of the animals of the time were probably soft bodied and hence not suitable for fossilization. Furthermore,

whatever fossil records might have been preserved have been largely destroyed by subsequent metamorphism.

In spite of the paucity of animal fossils, there is abundant evidence of the widespread occurrence of bacteria and algae throughout the Proterozoic. Extensive sedimentary iron-ore deposits of Proterozoic age occur in the Lake Superior district, and it is thought, with good reason, that bacteria were concerned with their formation. In fact, fossil bacteria closely resembling living iron bacteria have been reported from this region, while fossil bacteria looking like nitrifying forms have been found in Proterozoic rocks of Montana. Some of the Proterozoic limestones, reaching a great thickness, are made up in part of what are considered to be the secretions of calcareous algae similar to those formed by existing blue-green algae. In fact, many types of fossil algae have been described from Proterozoic strata.

Early Stages in Evolution.—There are three reasons for supposing that bacteria may have been the first forms of life to have existed on the earth: (1) Bacteria are the simplest and smallest of all existing organisms. (2) Because they are chief agents in effecting the decomposition of all dead organic matter, a world devoid of bacteria is inconceivable. (3) Although most bacteria are saprophytic or parasitic, and so could not exist in the absence of other forms of life, some can make food directly from water and carbon dioxide (or carbonates) without the aid of chlorophyll and light. Examples are the nitrifying bacteria, iron bacteria, sulphur bacteria, etc. Instead of utilizing solar energy, these plants obtain energy from the oxidation of various inorganic compounds (see p. 318).

A later stage in the development of life may have been the appearance of simple algae—green plants able to carry on photosynthesis by the utilization of solar energy. Simple blue-green algae must have appeared first, since they most closely resemble bacteria. Simple unicellular animals probably evolved at an early period, but obviously animals must have followed, not preceded, the appearance of plants. The first animals may have arisen either during the bacterial or algal stage. Perhaps they were derived from free-swimming green organisms similar to some of the existing flagellates (see p. 32). When the evolution of the first multicellular organisms occurred is unknown, but it

must have been early, as primitive invertebrates were certainly present in the Proterozoic.

TIME SCALE	ERAS	PERIODS	DOMINANT ANIMALS	DOMINANT PLANTS
	CENOZOIC	Quaternary	Mammals	Angiosperms
50		Tertiary		
	MESOZOIC	Upper Cretaceous	Reptiles	
100		Lower Cretaceous		Gymnosperms
150		Jurassic		
200		Triassic		
	PALEOZOIC	Permian	Amphibians	Pteridophytes and Primitive Gymnosperms
250		Upper Carboniferous		
300		Lower Carboniferous		
350		Devonian	Fishes	Primitive Pteridophytes
400		Silurian		
450		Ordovician	Higher Marine Invertebrates	Algae
500		Cambrian		
550				

FIG. 246.—Table of later geologic time. The figures in the time scale represent millions of years. (*Time estimates after C. A. Reeds*, 1931.)

THE PALEOZOIC ERA

The fossil record really begins with the Paleozoic, since so little is known of the life of the Archeozoic and Proterozoic. During the third great era, much progress was made in the development both of plants and of animals. At first all life was aquatic, being probably confined to the margins of shallow epicontinental seas. But early in the Paleozoic a momentous

forward step was taken—the first land plants and air-breathing animals appeared. As a result, great possibilities were opened for further evolutionary progress, and many of these were realized before the era closed.

The total duration of the Paleozoic was about 355 million years, only slightly more than half that of the Proterozoic, but greater than the combined duration of the two following eras. It comprises seven periods that fall into three groups, each characterized by a definite advance in life (Fig. 246).

Cambrian and Ordovician.—With the beginning of the Paleozoic era, an extensive development of life had been reached, since Cambrian fossils are very numerous and diverse. They are, however, entirely of marine invertebrates. No trace has ever been found in Cambrian beds of land animals or of vertebrates. The dominant and most highly developed forms were *trilobites*, a group of primitive crustaceans. They flourished during the entire Paleozoic and at its close became extinct. *Brachiopods* were nearly as abundant as trilobites; they were shelled, mollusk-like animals of which only a few still survive in deeper parts of the ocean. Sponges, coelenterates, echinoderms, and true mollusks were also present in the Cambrian seas. In fact, nearly all the great invertebrate groups were represented. Fossil algae furnish the only record of the plant life of the period, but algae must have been very abundant to have supported such a luxuriant marine fauna. It seems likely that primitive non-woody plants, perhaps somewhat similar to modern bryophytes, were becoming established on land, but if land plants were present during the Cambrian, they have left no fossil record.

During the Ordovician, marine invertebrates remained dominant but reached a higher stage of progress. At this time the trilobites reached their climax, that is, they made their greatest display in number of species and individuals (Fig. 247). They were exceeded numerically, however, by the brachiopods, while the largest and most powerful animals of the time were *cephalopods*, a group of true mollusks. Some of the latter were 12 to 15 feet long, and all of them had a shell like that of the modern chambered nautilus except that it was not coiled, in most cases, but straight or slightly curved.

During the Ordovician, the first fishes appeared. They were primitive, armored, bottom-dwelling forms known as *ostraco-*

derms and were not common. Figure 248 shows an ostracoderm belonging to a later geologic period. It has not been determined from which invertebrate group the first vertebrates arose. Like

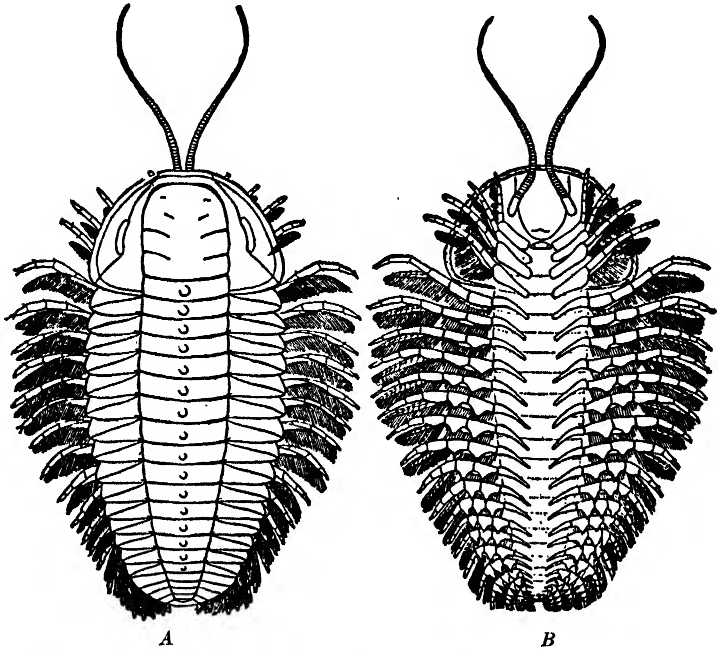


FIG. 247.—An Ordovician trilobite (*Triarthrus becki*), restored, twice natural size. *A*, dorsal view; *B*, ventral view. (*From Beecher.*)

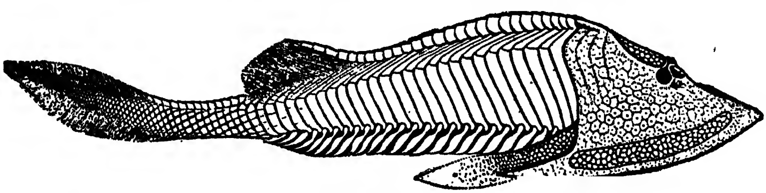


FIG. 248.—Restoration of *Cephalaspis*, a Devonian ostracoderm, side view. Length about 6 inches. (*From Patten, "Evolution of the Vertebrates and Their Kin," P. Blakiston's Son & Company, by permission.*)

the cyclostomes (see p. 180), to which they are related, the ostracoderms had a cartilaginous skeleton and were without true jaws and paired fins.

There is no record of land plants in the Ordovician deposits, but it is thought that pteridophytes were in existence then because of their abundance during subsequent periods.

Silurian and Devonian.—During the Silurian, ostracoderms became abundant, while sharks, representing a distinctly higher type of fishes, made their appearance. Like the ostracoderms, they had external armor and a cartilaginous internal skeleton. These early sharks were very primitive and not common. The trilobites, which culminated in the Ordovician, were reduced in number of species by approximately one-half. Some of them, by the development of spines and tubercles, presented a bizarre appearance. Other marine invertebrates were abundant, the brachiopods maintaining their numerical superiority. The cephalopods were more complex and remained powerful, but were gradually being displaced by the fishes. Corals and echinoderms (particularly crinoids) made a great display. A notable feature of the Silurian was the appearance of scorpions, the oldest known air-breathing animals. Plant remains consist mainly of algae, but the remains of a few primitive pteridophytes have been found, these representing the oldest known land plants.

FIG. 249.—*Dinichthys*, an arthrodiran from the Devonian shales of Ohio. Length 8 feet. (*Courtesy of American Museum of Natural History.*)

The Devonian marks the period when the fishes became the dominant animal group, displaying a great variety of types. The ostracoderms soon became extinct, but the *arthrodirans*, which possibly were descended from them, rose into prominence. The arthrodirans were the most numerous and the largest fishes of the time (Fig. 249). Some of them reached a length of 20 feet. The sharks of the Devonian were also abundant and powerful, some of them being 6 feet long. Other primitive types,

such as the *ganoids* and *lungfishes*, made their appearance (Fig. 250), but there were no representatives of the *teleosts* (bony fishes), the great modern group that includes over 95 per cent of all living species. Brachiopods were the most abundant marine invertebrates, while the trilobites declined still further.

Physical conditions during the late Silurian and early Devonian were favorable for the origin of land animals. Increasing aridity, causing a drying up of lakes and streams, may have furnished a stimulus that resulted in their appearance. The air-breathing invertebrates of the Devonian, so far as known, included scorpions, myriapods, and snails, but land vertebrates were also present, although very rare. In fact, the only evidence of their

FIG. 250.—Restoration of Devonian fishes from the Old Red Sandstone of Scotland. 1, an ostracoderm; 2, arthrodirans; 3 and 4, sharks; 5, 6, and 7, ganoids; 8, lungfishes. (*Courtesy of American Museum of Natural History.*)

existence consists of a single three-toed footprint found in Pennsylvania in a late Devonian deposit.

The land plants of the early and middle Devonian were chiefly primitive pteridophytes like those of the Silurian, while those of the later Devonian were advanced types including both pteridophytes and primitive gymnosperms. Some of the latter were fern-like plants with seeds, appropriately called "seed ferns."

Carboniferous and Permian.—The oldest amphibian remains, recognizable with certainty as such, have been found in Lower Carboniferous (Mississippian) deposits. Amphibians were not abundant at this time, however, and were mostly of small simple types somewhat resembling modern salamanders. It was once thought that the first land vertebrates evolved from ancient lungfishes, but there is now evidence that they were derived from primitive fringe-finned ganoids. The fishes were still a

mighty group during the Lower Carboniferous. The arthrodirans became extinct early in the period, but the sharks reached their point of greatest abundance. Most of them were ancient shell-feeding types that later became almost extinct.

In the Upper Carboniferous (Pennsylvanian) the amphibians were the dominant animal group and reached the highest point

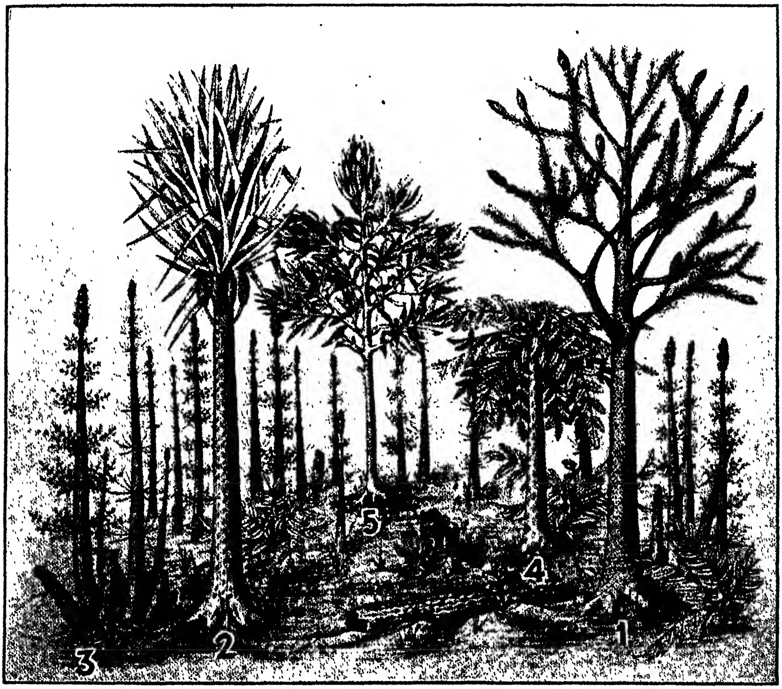


FIG. 251.—A composite group of leading plants of the Upper Carboniferous. 1, *Lepidodendron* and 2, *Sigillaria*, gigantic lycopods; 3, *Calamites*, a horsetail; 4, a seed fern; 5, *Cordaites*, a primitive gymnosperm. (*From Chamberlin and Salisbury, "College Geology," Henry Holt & Company, by permission.*)

in their development. Many peculiar types were evolved, some with curious proportions, such as a small body with a large flat head. In the Upper Carboniferous strata primitive reptiles have been found, but many are so closely similar to amphibians that it is difficult to recognize them. The earliest known insects are of Upper Carboniferous age, but this group must have originated earlier in the Paleozoic, for here we find an abundance of them and a marked development of the primitive orders. Compared to modern insects, these Carboniferous forms were gigantic.

Cockroaches 4 inches long were not rare, while some of the dragonflies were 15 inches long and had a wingspread of 30 inches. No larger insects have ever lived. Spiders, scorpions, myriapods, and snails were also common on land.

A warm, moist, uniform climate prevailed throughout the Upper Carboniferous, and this favored the development of a most luxuriant vegetation. It was during this period that our most extensive coal deposits were laid down. Coal represents accumulated plant remains subsequently metamorphosed by geologic agencies. Over immense areas there extended great swamp forests consisting chiefly of gigantic lycopods and horsetails, as well as seed ferns and other primitive gymnosperms (Fig. 251). Some of these plants reached a height of 100 feet.

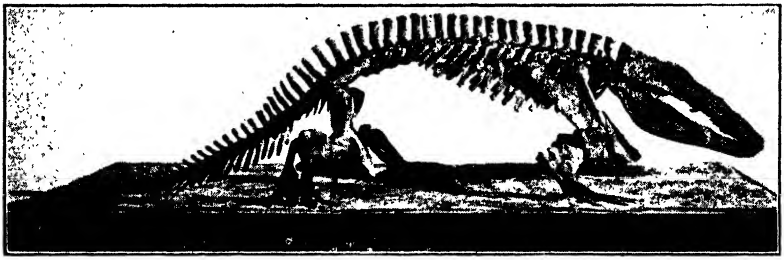


FIG. 252.—Skeleton of *Eryops*, an amphibian from the Permian of Texas. Length about 10 feet. (*Courtesy of American Museum of Natural History.*)

Although the amphibians passed their climax in the Upper Carboniferous, they were still abundant in the early Permian. Some reached a length of 10 feet (Fig. 252). Primitive reptiles became common, but most of them were still amphibian-like. The vegetation underwent marked changes, the older pteridophyte types declining and gymnosperms becoming more highly developed. The Permian is the last period of the Paleozoic era, and toward its close great geologic changes that exerted a profound influence upon life took place. In North America, the event of greatest magnitude was the formation of the Appalachian Mountain System. Widespread aridity and glaciation occurred during the Permian, making conditions so severe that many forms of life were unable to survive into the next era.

THE MESOZOIC ERA

The close of the Paleozoic marks the decline of the amphibians and the beginning of reptilian ascendancy. The Mesozoic era, the

duration of which is estimated at 135 million years, is appropriately called the "Age of Reptiles," for at that time they reached their greatest display, dominating all other animal groups. The Mesozoic includes four periods: the *Triassic, Jurassic, Lower Cretaceous* and *Upper Cretaceous* (Fig. 246).

Life of the Triassic.—From a few simple reptilian types that lived over from the Permian into the Triassic, there arose many new groups, such as dinosaurs, pterosaurs, ichthyosaurs, plesiosaurs, and turtles. The first *dinosaurs* were of small or medium size, lizard-like, and relatively unspecialized; thousands of their footprints are preserved in the Triassic sandstones of the Connecticut Valley. The dinosaurs became the most abundant and characteristic land animals of the Mesozoic. The *pterosaurs* were flying forms and in many ways the most remarkable of all reptiles. The *ichthyosaurs* and *plesiosaurs* were lung-breathing aquatic reptiles descended from terrestrial ancestors; they were rare in the Triassic and but little specialized for marine life.

The appearance of primitive mammals was a notable feature of the Triassic. They were small, reptile-like, egg-laying forms, perhaps somewhat like modern monotremes and probably insectivorous in their habits. These little creatures were very insignificant members of the Triassic fauna. In fact, mammals remained comparatively rare throughout the Mesozoic and made little evolutionary progress, their subordinate position doubtless being due to the supremacy of the reptiles. The plant life of the Triassic was characterized by the appearance of new and higher types of gymnosperms, which were the dominant plant group. Some of these gymnosperms were much like modern cycads, others like conifers. The trees in the petrified forests of Arizona, for example, which are of early Triassic age, are all conifers (Fig. 241). Nearly all the giant lycopods and horsetails, as well as the seed ferns and other primitive gymnosperms of the Paleozoic, had become extinct before the close of the Permian, but a few persisted into the early Triassic. True ferns, however, became more abundant.

Life of the Jurassic.—Beginning with the Jurassic, and continuing through the Cretaceous, the reptiles reached the height of their ascendancy. They dominated the sea, the land, and the air. The ichthyosaurs, the most highly specialized of marine reptiles, attained their climax early in the Jurassic. They were

distinctly fish-like in appearance, with paddle-like limbs, a dorsal and a caudal fin, a short neck, and a slender pointed snout

FIG. 253.—*Ichthyosaurus*, a highly specialized marine reptile from the Jurassic of Germany. Length 25 to 30 feet. The ichthyosaurs were viviparous; the figure represents a mother with brood of young. (*Courtesy of American Museum of Natural History.*)

armed with numerous sharp teeth (Fig. 253). Some of the ichthyosaurs attained a length of 30 feet. Crocodiles and true lizards made their first appearance in the Jurassic.

The most numerous and most powerful land reptiles were the dinosaurs, which by the end of the Jurassic reached their cul-

mination, there then being the greatest variety and the largest ones that ever existed. Nearly all the Triassic dinosaurs were carnivorous, but during the Jurassic both carnivorous and herbivorous types were common, the former preying upon the latter. These flesh-eaters were powerful creatures 30 to 35 feet

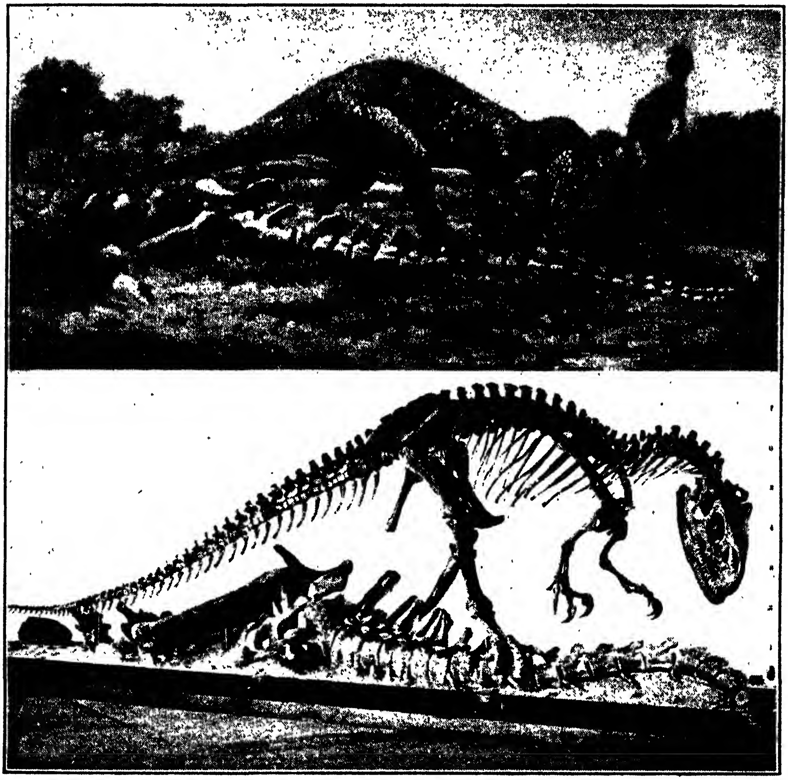


FIG. 254.—Skeleton of the bipedal carnivorous dinosaur *Allosaurus* and restoration of the same. The creature is shown preying upon one of its herbivorous contemporaries. Length of specimen 34 feet. *Allosaurus* lived in North America during late Jurassic and early Cretaceous times. (*Courtesy of American Museum of Natural History.*)

long, with hind legs much larger than the fore legs and alone used in walking (Fig. 254). The jaws, often 3 feet in length, bore numerous sharp teeth. All the digits were provided with large, sharp, curved claws.

Some of the smaller herbivorous dinosaurs were bipedal, like the carnivorous forms, but all the larger ones walked on all

four legs. One of the largest of these creatures was *Brontosaurus*, with a length of nearly 70 feet and an estimated weight of 37 tons (Fig. 255). *Diplodocus* reached a length of 80 to 90 feet,

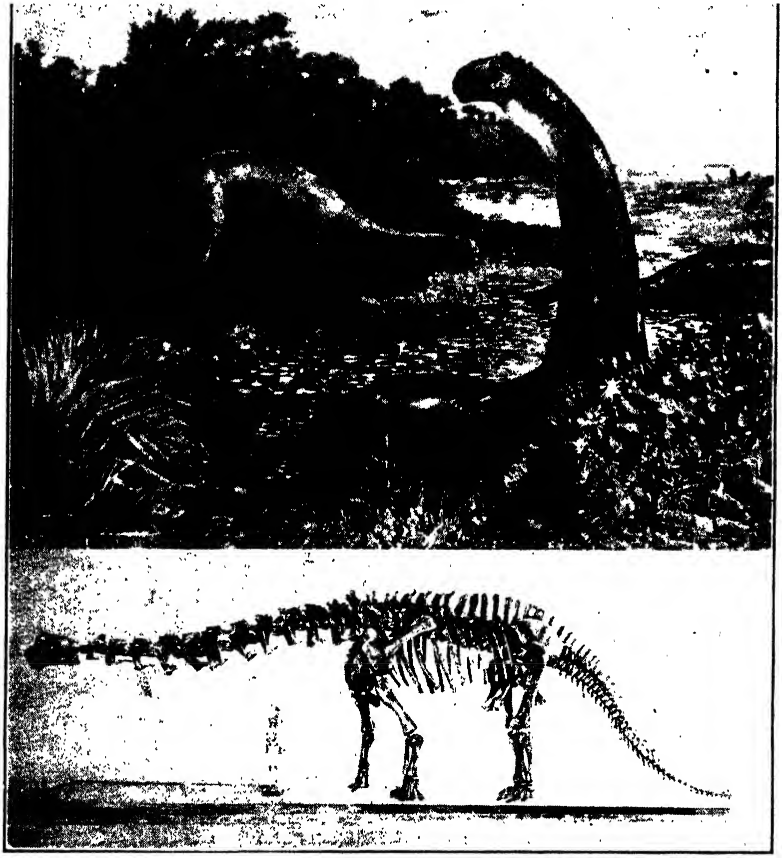


FIG. 255.—*Brontosaurus*, a gigantic, quadrupedal, herbivorous dinosaur from the late Jurassic of Wyoming. Length 66 feet, and estimated weight 37 tons. This creature inhabited swampy meadows and flood plains. (*Courtesy of American Museum of Natural History.*)

but the body was less bulky and the tail considerably longer. In all these herbivorous giants the head was comparatively small, the neck and tail long, and the legs massive. The toes were short and the claws blunt. These huge beasts were sluggish in their movements and probably lived in swamps. No larger land animals have ever inhabited the earth.

Another group of quadrupedal Jurassic dinosaurs of herbivorous habits were the grotesque armored forms, with narrow bodies having great plates projecting upward from the back and long spines on the tail. *Stegosaurus*, one of the best known of these dinosaurs, reached a length of about 20 feet (Fig. 256). The head, which was unusually small, had beak-like jaws and a tiny brain that weighed about 2½ ounces. *Stegosaurus* must have been extremely stupid and sluggish, relying upon its armor for protection against its more active flesh-eating contemporaries.

The pterosaurs made progress during the Jurassic and became more numerous. The largest ones had a wingspread of about

FIG. 256.—Restoration of the armored dinosaur *Stegosaurus*, a quadrupedal herbivorous form of Jurassic age. Length about 20 feet. (*Courtesy of American Museum of Natural History.*)

3 feet. Most of these flying reptiles had bird-like heads with teeth in their jaws, and some had rudder-like tails. The wings stretched from the fore limbs to the hind limbs and body, as in modern bats, but were supported by only one elongated digit.

The oldest fossil birds are known from the Jurassic, but the group must have originated earlier, possibly in the Permian. They did not evolve from pterosaurs, as the structure of their wings clearly shows, but from some more remote reptilian stock. In the lithographic limestone of Bavaria two complete skeletons have been found of a very primitive bird called *Archaeopteryx* (Fig. 257). It is clearly a transitional form between reptiles and birds—a true connecting link. The animal was about the size

of a crow. Its most distinctive avian features were the shape of its head and the presence of wings and feathers. Some of its

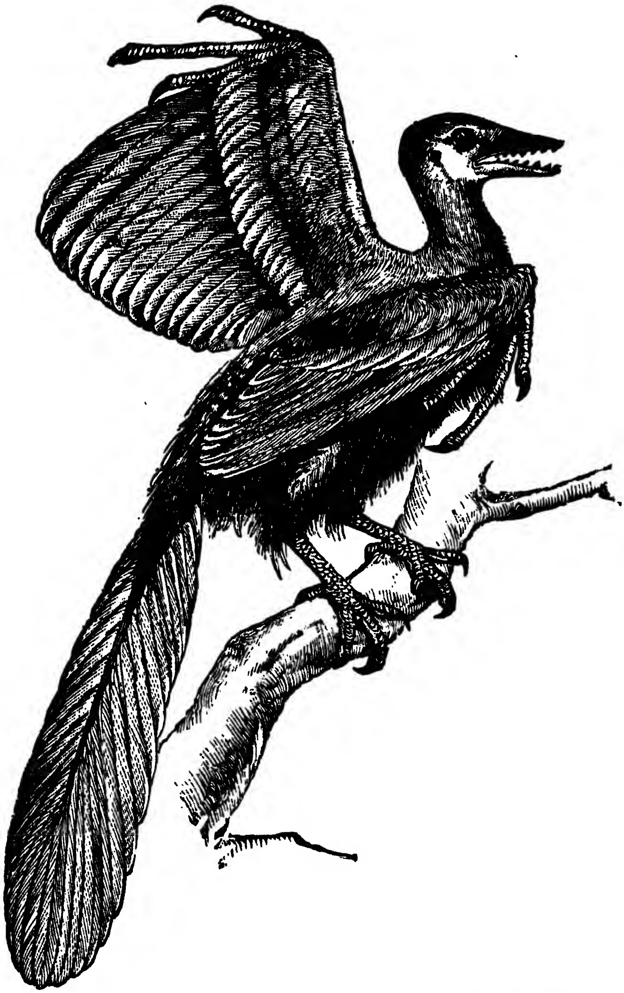


FIG. 257.—Restoration of *Archaeopteryx*, a primitive Jurassic bird showing many reptilian features, × ⅓. (*From Romanes, "Darwin and after Darwin," Open Court Publishing Company, by permission.*)

conspicuous reptilian characters were a long vertebrated tail, separate pelvic bones, wings with three free, clawed digits, and teeth in both jaws.

Another feature of the Jurassic was the appearance of the teleosts, or bony fishes. Before the end of the Mesozoic they had become the dominant group of aquatic vertebrates, a position which they have held ever since.

Life of the Cretaceous.—The life of the Cretaceous presents two important developments, *viz.*, the extreme specialization and final extinction of the great reptiles, and the appearance of angiosperms. Of the dinosaurs that evolved during the Jurassic,

Fig. 258.—*Tyrannosaurus*, a highly specialized carnivorous dinosaur attacking *Triceratops*, a horned herbivore. Both forms lived during the Upper Cretaceous. (*Courtesy of American Museum of Natural History.*)

the large carnivorous forms lived well into the Cretaceous but finally died out and were succeeded by huge specialized creatures that surpassed even them in ferocity. Of the Upper Cretaceous flesh eaters, the most notable was *Tyrannosaurus* (Fig. 258). This terrible beast, nearly 50 feet in length and with jaws 4 feet long, was "in respect to speed, size, power, and ferocity the most destructive life engine which has ever evolved" (Osborn).

Most of the gigantic herbivorous dinosaurs became extinct shortly before or soon after the beginning of the Cretaceous, but their place was taken by other groups. One of these, the duckbill dinosaurs, were bipedal forms with webbed feet and a long flat

tail; they fed upon the vegetation of swamps and marshes (Fig. 259). Another group of herbivores were the horned dinosaurs of the Upper Cretaceous. These curious dinosaurs were 20 to 25 feet long, very bulky, and quadrupedal (Fig. 258). The head was large, the tail relatively short, and the limbs short but massive. Horns were present on the head, three of them in *Triceratops*, and a massive bony frill occurred over the neck. As in the duckbill dinosaurs, the jaws were beaked and only back teeth

FIG. 259.—Restoration of the duckbill dinosaur *Trachodon*, a bipedal herbivorous form of Upper Cretaceous age. Length about 25 feet. (*Courtesy of American Museum of Natural History.*)

were present; these were used for grinding vegetable food. The horned dinosaurs were among the last to become extinct at the close of the Mesozoic. Mighty battles must have been waged between *Tyrannosaurus* and *Triceratops*, the former representing the climax of dinosaurian offense, the latter of defense.

Like the dinosaurs, the flying reptiles of the Upper Cretaceous also became highly specialized. One of them (*Pteranodon*) with a small body, had a wingspread of 20 feet (Fig. 260). It was the largest and most highly specialized flying creature that has ever lived. Like modern birds, most of the Upper Cretaceous

pterosaurs were short tailed and toothless. The birds of the Cretaceous period, so far as known, were specialized for diving, some being large forms incapable of flight, and all having teeth.

Of the aquatic reptiles, the ichthyosaurs declined rapidly during the Upper Cretaceous, while the plesiosaurs reached their culmination (Fig. 261). The latter were less fish-like than the former, the head being smaller and the neck longer. The Jurassic plesiosaurs were not much over 20 feet long, but the largest of the Cretaceous forms (*Elasmosaurus*) exceeded 40 feet in length,

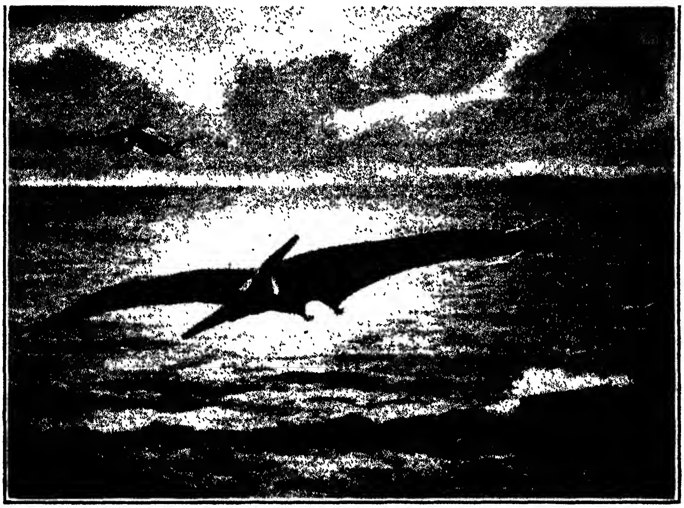


FIG. 260.—Restoration of *Pteranodon*, an Upper Cretaceous pterosaur with a wingspread of nearly 20 feet. (*Courtesy of American Museum of Natural History.*)

over half of which was neck. In addition to marine turtles and crocodiles, *mosasaurs* were also abundant at this time. They were gigantic, carnivorous, marine lizards, some reaching a length of 40 feet (Fig. 262).

During the early part of the Lower Cretaceous the flora consisted of ferns, cycads, and conifers—groups that had flourished during the Triassic and Jurassic. But with the appearance of the angiosperms later in the period, these ancient types declined. The evolution of the first angiosperms was so remarkably rapid that by Upper Cretaceous times they had spread over the entire earth, dominating the vegetation and giving it a distinctly modern aspect. In fact, such familiar trees as willows, oaks,

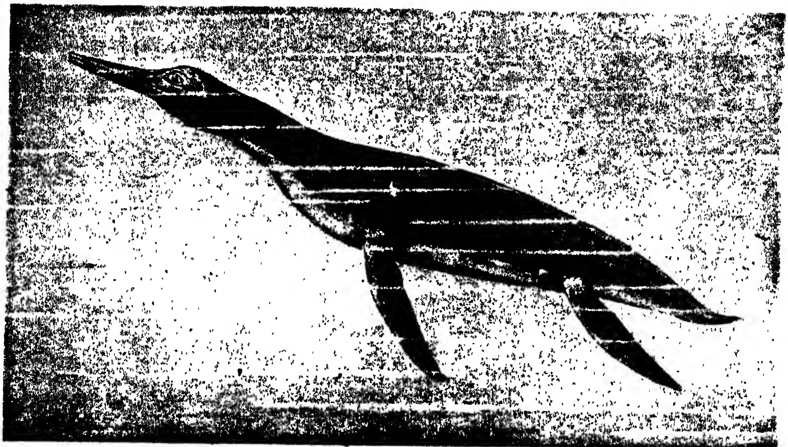


FIG. 261.—Restoration of *Trinacromerum*, an Upper Cretaceous plesiosaur. Length about 10 feet. (*From Williston, "Water Reptiles of the Past and Present," University of Chicago Press, by permission.*)

FIG. 262.—*Tylosaurus*, a mosasaur from the Upper Cretaceous of Kansas, chasing the giant fish *Portheus*. These sea lizards attained a length of 40 feet. (*Courtesy of American Museum of Natural History.*)

elms, figs, tulip trees, magnolias, maples, sassafras, and palms were common.

The close of the Mesozoic was characterized by stupendous geologic changes that took their toll of life, just as had previously taken place at the end of the Paleozoic. For example, the formation of the Rocky Mountain System occurred at this time. With radical changes in environment going on all over the earth, great extinctions of life occurred. Just what factors were responsible for bringing about the ultimate extinction of the great Mesozoic reptiles may perhaps never be known. But, after holding sway for approximately 135 million years, they did disappear from the earth, leaving to represent them today only the lizards, snakes, turtles, and crocodiles—all insignificant members of the modern fauna.

THE CENOZOIC ERA

Approximately 60 million years have elapsed since the beginning of the Cenozoic, the duration of which is therefore less than half that of the Mesozoic. It is characterized as the "Age of Mammals" and represents the most recent chapter in the history of life. The Cenozoic includes two periods of very unequal length: the *Tertiary*, which terminated approximately 1 million years ago, and the *Quaternary*, the period in which we are now living.

The following table will be useful for reference in connection with the ensuing discussion of mammalian evolution:

Era	Periods	Epochs	Duration, years
Cenozoic	Quaternary	Recent	25,000
		Pleistocene	1,000,000
	Tertiary	Pliocene	6,000,000
		Miocene	12,000,000
		Oligocene	16,000,000
		Eocene	20,000,000
		Paleocene	5,000,000

Life of the Tertiary.—As already noted, primitive egg-laying mammals arose early in the Mesozoic but remained rare and

made little progress throughout the era. At the close of the Mesozoic, however, the extinction of the great reptiles gave these ancestral mammals an opportunity of which they took immediate advantage. Mammalian ascendancy began early in the Tertiary, true placental forms being found in the Paleocene beds. These early Tertiary mammals were small generalized forms, with small brains but far more intelligent than any of the reptiles. Nearly all of them had the primitive number of teeth (44), which developed in two sets but showed little differentiation. Their feet were pentadactyl and mainly plantigrade. These *archaic mammals*, as they are called, included some groups that soon became extinct but also others (such as insectivores, bats, and primates) which gave rise to modified descendants that still live.

At the beginning of the Eocene there appeared in both Europe and North America, as invaders from another part of the world, mammals of more advanced types. These gradually displaced most of the archaic forms. Nearly all the modern orders were differentiated at this time, and some were present that have no modern representatives. Adaptation to different modes of life resulted in the development of diverse types. This adaptive radiation of mammals continued throughout the Oligocene, when many new forms arose more nearly like those of the present. During the Miocene the mammals made a remarkable display, reaching their climax during the late Miocene or early Pliocene, and, except for man, have been a steadily declining group ever since. Birds were probably numerous throughout the Tertiary, as they are today, but little is known regarding their fossil history.

The vegetation of the Tertiary was characterized by the great abundance and rapid evolution of the angiosperms, particularly of the younger herbaceous groups. A warm moist climate prevailed in most parts of the world during the early part of the period. In fact, in the Eocene such tropical plants as figs, magnolias, palms, laurels, and breadfruit trees grew in parts of Europe and North America now temperate, while even Greenland had a rich temperate flora. The later Tertiary was distinctly cooler, while the Quaternary marked the advent of the Great Ice Age.

Life of the Quaternary.—The most notable feature of this last period in geologic history was the extensive glaciation that occurred during the Pleistocene as a result of great climatic changes. In North America five distinct glacial invasions took place, separated by long intervening warm stages. The beginning of the Recent period dates from the withdrawal of the last ice sheet; since then about 25,000 years have elapsed.

The oncoming of each successive glacial advance resulted in wholesale migrations and extinctions of life. Arctic animals and plants came southward, while temperate forms retreated to more genial regions. During the warm interglacial stages, an abundant and varied fauna occupied temperate North America, including giant ground sloths, horses, tapirs, peccaries, camels, deer, antelopes, bison, mastodons, mammoths, beavers, wolves, bears, and saber-toothed cats. A notable collection of Pleistocene mammals has been obtained from the asphalt pits of southern California (Fig. 240).

The most outstanding event in the history of life during the Quaternary period has been the evolution of man. There is conclusive proof that man lived in Europe throughout the greater part of the Pleistocene, but there is no undisputed evidence of his existence in North America during this time. Human evolution forms the subject of Chap. XXIII.

EVOLUTION OF THE HORSE AND ELEPHANT

Because the Cenozoic deposits have been formed during relatively recent times, much has been learned concerning the life of this era. The evolution of many mammalian groups has been thoroughly traced, examples being the carnivores, camels, pigs, ruminants, horses, tapirs, rhinoceroses, and elephants. The evolution of horses and elephants is so well known that no account of paleontology would be complete without a brief consideration of their fossil history.

Adaptive Features of Modern Horses.—Modern horses and those of the Pleistocene belong to the genus *Equus*, a highly specialized branch of ungulate stock. Specialization has progressed along two general lines: for rapid running over hard ground, and for grazing. The structure of the horse has been modified in accordance with these functions. Thus the legs

are very long and slender and can bend only in one plane. In the fore limb, the ulna has become greatly reduced in size and has fused with the enlarged radius, while in the hind limb the fibula has similarly united with the tibia, the former being very small and the latter large. The wrist and heel do not touch the ground, the foot consisting of a single, enlarged, functional toe that corresponds to the middle digit of a pentadactyl limb, and of two slender "splint bones," representing the remnants of the second and fourth digits (Fig. 213*C*). The horse walks upon the tip of the toe, this being provided with a large hoof. Modern horses are about 5 feet or more in height.

In order to permit the head to reach the ground without the necessity of the animal's bending its knees, both the skull and the neck have become lengthened. The elongated skull, with its large deep jaws, also provides room for the development of the teeth (Fig. 263). The incisors, which function as cropping teeth, are very large and strong. The canines are greatly reduced in the male, and usually are entirely absent in the female. The premolars and molars are similar in form and function, being broad, flat, and modified for grinding. They are very high crowned and are provided with a complex masticating surface. The grinding teeth continue for a long time to grow in height as they are worn down.

Stages in Equine Evolution.—The evolution of the horse took place chiefly in North America. It has been traced through a number of successive stages, some of which will now be considered.

The most primitive genus of horses is *Eohippus*, a form that lived in North America and Europe during early Eocene times (Fig. 263). *Eohippus* was a slender animal about a foot in height, or about the size of a fox. Its head, neck, and limbs were relatively short and the two bones comprising the forearm, as well as those of the shank, were not yet fused. It had a complete set of 44 teeth. The grinding teeth were low crowned, the masticating surfaces having a primitive pattern. The fore limbs of *Eohippus* bore four functional toes, the hind limbs three. There was no trace of the first digit on the fore feet, but on the hind feet vestiges of both the first and fifth digits were present. Thus there can be no doubt that *Eohippus* was the descendant of a five-toed ancestor.

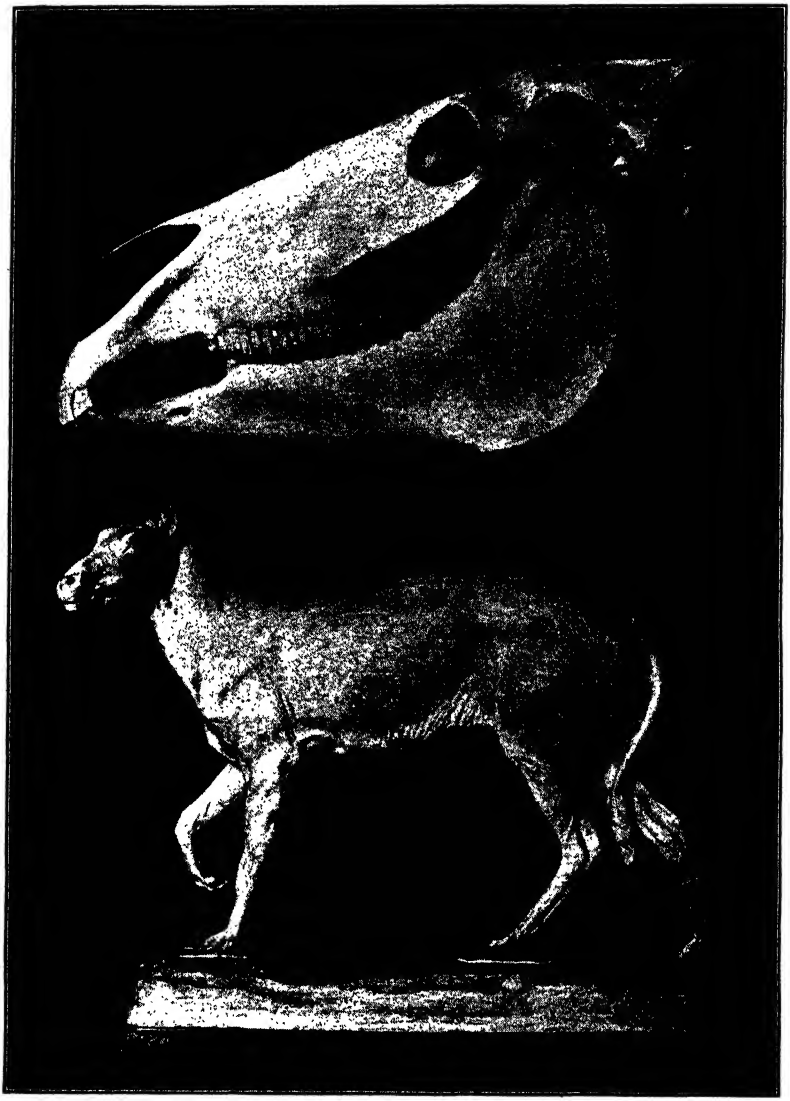


FIG. 263.—Skull of modern horse (*Equus*) and model of Eocene horse (*Eohippus*) photographed to same scale. (*Courtesy of American Museum of Natural History.*)

The second horse in our series is *Orohippus*, whose remains have been found in the middle Eocene deposits of North America. It was only slightly larger than *Eohippus*, and the number of functional digits was the same, but the third toe on both the fore and hind feet was larger and the vestigial digits had disappeared from the latter. The teeth of *Orohippus* were but slightly more advanced than those of its forerunner.

Mesohippus was a North American horse that lived during the Oligocene. It was 18 to 24 inches tall, or about the size of a sheep. Its head, neck, and limbs were longer than those of its progenitors, but the skull was still relatively short and unspecialized. The ulna was very slender but still distinct, while the fibula had become greatly reduced and was partly fused with the tibia. Each foot was provided with three functional toes, the middle one being the largest. The fore limbs bore a vestige of the fifth digit. The teeth of *Mesohippus* were low crowned but more complex than those of the Eocene horses.

Merychippus lived in North America during the Miocene. It was considerably larger than its forerunners, being 3 to 4 feet in height. Its skull was longer and its lower jaw heavier. In this horse the radius and ulna were completely fused. All the feet were three toed, but the middle digit was relatively larger than in *Mesohippus*, while the two lateral ones did not touch the ground. The grinding teeth were relatively high crowned and their surfaces somewhat complex, but they were incapable of continued growth. *Merychippus* is thought to have been the first horse to have turned from a browsing to a grazing habit. The Miocene was an epoch of continental elevation, involving an extensive development of prairies and areas suitable for grazing, and a disappearance of the older forested regions. Most of the browsing types of mammals became extinct in North America at this time, while forms capable of becoming adapted to a grazing habit, like *Merychippus*, flourished.

Pliohippus was a late Pliocene form, not much larger than *Merychippus*, but advanced in other ways. The two lateral toes were reduced to splint bones, while the teeth were more highly crowned and had complex grinding surfaces. *Pliohippus* gave rise to *Equus*, which spread from North America to South America, Europe, Asia, and Africa but for some unknown reason became extinct on the American continents and in Europe during

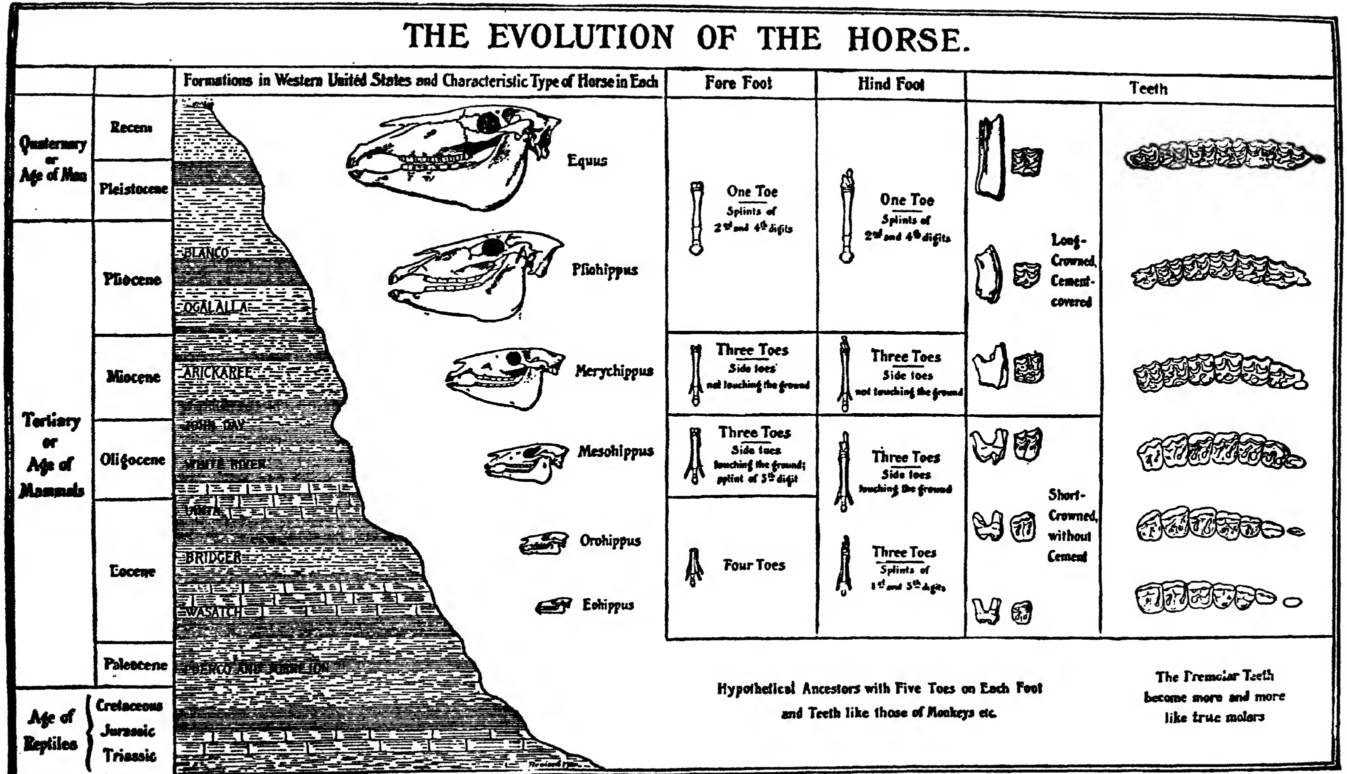


FIG. 264.—Diagram showing the evolution of the horse. (*From Matthew, in Quarterly Review of Biology*, 1926, *by permission.*)

the Pleistocene, surviving only in parts of Africa and Central Asia.

Figure 264 graphically presents the evolution of the horse through the six stages described above and should be carefully studied. It must be understood that, in addition to these six stages, a number of transitional forms have been found in intermediate strata, giving an unbroken evolutionary series from the early Eocene to the present time.

Adaptive Features of Modern Elephants.—The genus *Elephas* includes two modern species of elephants and the extinct mam-

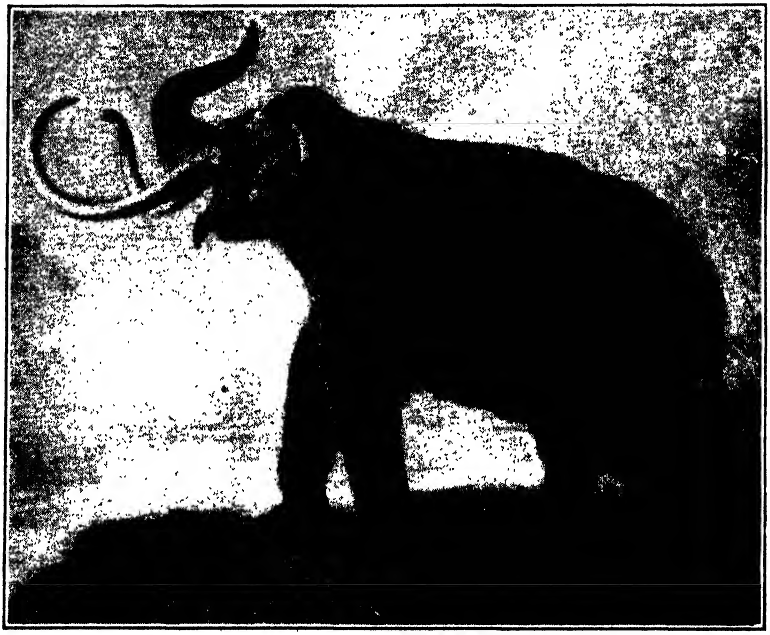


FIG. 265.—Restoration of imperial mammoth (*Elephas imperator*) by Charles R. Knight. (*Courtesy of American Museum of Natural History.*)

moths. During the Pleistocene the genus was widely distributed over Europe, Asia, and North America, but living elephants occur only in Asia and Africa.

With the exception of the whales, elephants are the largest living mammals. The Indian species attains a maximum height of 10 feet, while the largest African elephants are said to be nearly 13 feet tall. Some of the mammoths of the Pleistocene were as large or slightly larger than this (Fig. 265). The limbs of elephants are large and pillar-like, an obvious adaptation for

supporting the enormous weight of the body. The feet are five toed, each toe being hoofed. In most long-legged mammals the neck is also elongated to permit the head to reach the ground, but in elephants the massive head makes this arrangement impossible. Accordingly the trunk takes the place of a long neck. The trunk is a prolongation of the nose and upper lip; it is used chiefly in conveying food to the mouth.

The skull of the elephant is very short and high, being entirely out of proportion to its length. The brain is large—nearly twice as large as the human brain—but it does not fill the cranium, large air spaces being also present. The dentition of the elephant is highly specialized. The tusks are highly modified incisor teeth that reach an extreme length of 8 feet in the Indian elephant and 10 feet in the African species. In some of the mammoths the tusks were 16 feet long. Aside from the tusks, the only teeth that the elephant has are molars, and of these it never has more than four complete or eight partially worn ones at a time. As the grinding teeth are worn down, they move forward in the jaw, and are replaced by new ones appearing behind. The chewing surface is very complex, having in the African elephant up to 10 or 11 transverse ridges, in the Indian elephant and the extinct Siberian mammoth, up to 27.

Stages in Evolution of the Elephant.—There has been found in the upper Eocene and lower Oligocene deposits of Egypt a mammal called *Moeritherium*, generally recognized as the progenitor of modern elephants (Fig. 266). It was about 3½ feet in height, or about the size of a pig. It did not look like an elephant except in having a high skull, two short tusks in each jaw, and grinding teeth with two or three transverse ridges. It had no trunk, but the upper lip may have been prehensile. The neck was long enough to have enabled the head of the animal to reach the ground.

A form called *Paleomastodon* has been found in the lower Oligocene formations of Egypt and India. It was larger than *Moeritherium*, had a higher skull, a relatively shorter neck, and longer tusks, but the lower tusks were much shorter than the upper ones. The molar teeth were larger than in the earlier form, and the three transverse ridges were more conspicuous. The upper lip was slightly elongated and probably reached to the tip of the tusks.

Trilophodon lived during the Miocene in Europe, Africa, and North America. It was a large animal—almost as tall as the

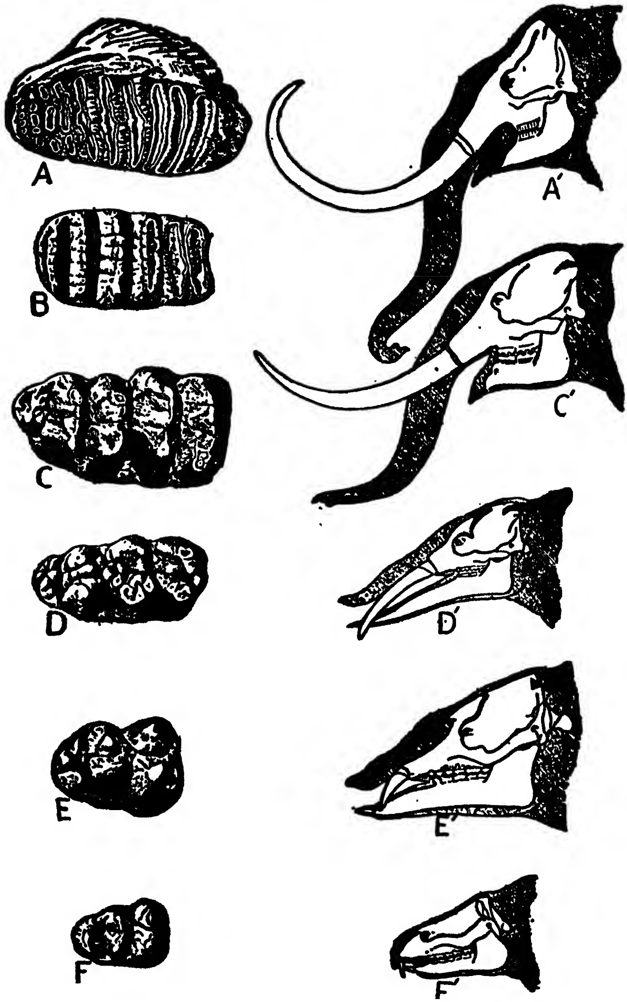


FIG. 266.—Evolution of the head and molar teeth of elephants; *A*, *A′*, *Elephas*, Pleistocene; *B*, *Stegodon*, Pliocene; *C*, *C′*, *Mastodon*, Pliocene; *D*, *D′*, *Trilophodon*, Miocene; *E*, *E′*, *Paleomastodon*, Oligocene; *F*, *F′*, *Moeritherium*, Eocene. *(From Lull, "Organic Evolution," The Macmillan Company, by permission.)*

modern Indian elephant. It made an advance over *Paleomastodon* in having longer tusks and more complex molars. The latter were large and reduced to the same number as in modern

elephants, but there were still only three transverse ridges. *Trilophodon* was peculiar in that its lower jaw was greatly elongated and provided with a pair of tusks. As compared to modern species, the trunk was short but probably reached as far as did the tusks.

Mastodon, of which several species are known, lived during the Pliocene and Pleistocene in North America, Europe, and Asia. The mastodons were larger than the earlier forms, being

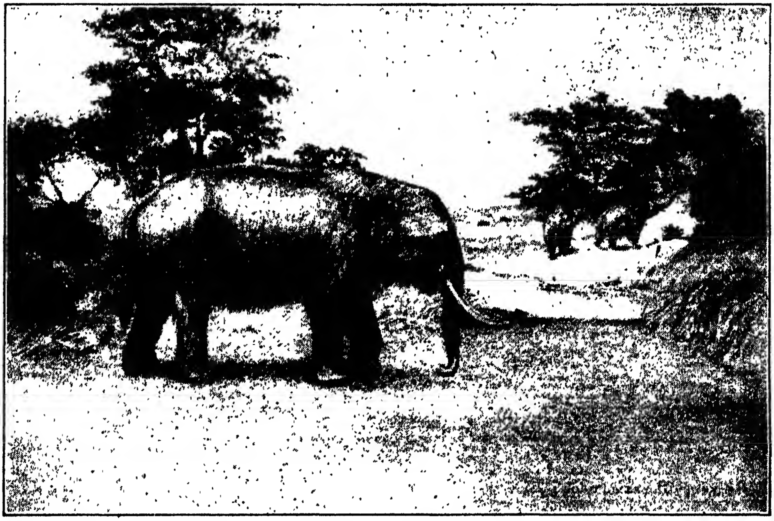


FIG. 267.—Restoration of American mastodon (*Mastodon americanus*) by John L. Ridgway. (*Courtesy of Los Angeles Museum of History, Science, and Art.*)

about the size of the modern Indian elephant, but they were stockier in build (Fig. 267). A pair of tusks was present only in the upper jaw; these were about 9 feet in length. The lower jaw was greatly shortened and the teeth reduced in number, there never being more than eight molars present at any time. The transverse ridges did not exceed five or six, three being the common number.

CONCLUSIONS

The facts of paleontology justify the drawing of certain general conclusions with reference to the course of organic evolution. These may be briefly stated as follows: (1) Throughout geologic history there has been an ascending succession of plant and

animal groups corresponding to the sequence of rock formations in which their remains are embedded. Thus each succeeding geologic period marks a progressive advance in life. (2) The general trend of evolution has been toward greater structural specialization in adaptation to particular conditions of living. This is shown by the fossil record of many groups. (3) Higher forms of life have sprung from generalized members of lower groups, not from specialized ones. (4) Forms highly modified for living under a particular set of external conditions cannot again become generalized, but can change only in the direction of greater specialization. (5) With a radical change in environment, specialized organisms are often unable to survive the new conditions and so become extinct.

CHAPTER XXII

THE CAUSES OF EVOLUTION

Some of the evidence upon which the principle of evolution rests has been examined, and it has been seen that all the facts presented in the last two chapters can be explained only on the basis of descent with modification. Biologists are unanimous in their conviction that evolution is a natural process. They are not in agreement, however, as to how the process operates—as to the causes underlying organic changes. This is because the method by which evolution has come about is imperfectly understood, and consequently a diversity of opinion exists as to what are the most important factors involved. A number of causative theories have been advanced, but none is entirely satisfactory. It is one thing to show that evolution has taken place but another thing to explain how it has taken place. So it must be borne in mind that, although proposed explanations may be discarded, the fact of evolution will always remain.

Theories of evolution are usually associated with modern times, but it should be realized that crude conceptions regarding the derivation of higher organisms from lower ones have existed from the time of the early Greek philosophers. It has only been since the beginning of the nineteenth century, however, that evolution has been the subject of scientific study. The older evolutionary conceptions were wholly speculative, but our modern theories of causation are based on careful observation and experimentation.

We shall consider only the three most important theories of evolution and take them up in the order in which they have been advanced.

INHERITANCE OF ACQUIRED CHARACTERS

That organisms can be modified through the action of external influences is a matter of general observation, and it has long been assumed that such induced changes are transmitted to subse-

quent generations. The greatest exponent of this idea as a cause of evolution was the French naturalist, Jean Baptiste de Lamarck (Fig. 268), whose theory was announced in 1801. An *acquired character* is a modification that arises as a direct response to an external stimulus, such as a change in environment or function. It is not part of the organism's inheritance, but something imposed upon it by the surroundings. Lamarck's theory is based on the idea that acquired characters are inherited

Fig. 268.—Jean Baptiste de Lamarck, 1744–1829.

—that individual adaptations become racial—that inheritance is modified by environment.

Direct Action of Environment.—Lamarck thought that modification arises somewhat differently in the case of plants and lower animals on the one hand, and higher animals on the other, although in both cases the causal agent is a change in environment. In the former the environment acts directly, in the latter, indirectly. Examples of structural changes induced by the environment have been given (see pp. 314–316). Lamarck assumed that the effects produced by a change in external conditions become cumulative through succeeding generations; he thought that racial characters have developed by the inheritance

of direct responses. According to this theory, the peculiar features of desert plants, for example, have resulted from the direct action of the desert conditions upon them, the changes induced in each generation being transmitted to subsequent generations.

FIG. 269.—Monterey cypress (*Cupressus macrocarpa*), a tree native to the central California coast in the vicinity of Monterey Bay. Exposed to the sea winds, the crown becomes very broad and flat, and the branches, often grotesquely bent and gnarled, tend to grow horizontally away from the wind. (*Courtesy of Professor Charles J. Chamberlain.*)

Although cases of individual adaptations are often striking, it must be realized that the power of adaptive response is limited. Only minor adjustments are possible. Even in the most plastic organisms the basic features are so firmly fixed by heredity that little or no alteration can take place. Many widely distributed organisms live under a great variety of conditions—most common weeds, for example—and yet in such cases members of the

same species often may exhibit relatively slight differences among themselves. On the other hand, members of the same species living under a uniform set of conditions may sometimes show considerable variation.

Another important point should be kept in mind. When organisms are placed in a new environment, as a rule the changes induced are not permanent, for when put back in the old environment the "acquired characters" become lost. Thus when seeds or cuttings of lowland plants are grown in alpine regions, the progeny often become highly modified. In fact they are said to become "transformed" into alpine species. But when taken back to the lowland, even after many generations of exposure to alpine conditions, they return to their original state. Trees indigenous to seacoasts are often highly modified by wind action, but when their seeds are planted under normal conditions no effect of the former environment remains (Fig. 269).

Use and Disuse.—Among the higher animals Lamarck thought that structural modification arises chiefly through changes in function, basing his belief on the fact that organs are strengthened through use and weakened through disuse. He thought that the environment does not act directly but indirectly, a change in external conditions causing an animal to experience new needs. These call for new habits and modes of life in accordance with which certain organs are used to a greater extent, others to a lesser extent. The former then tend to develop, the latter to atrophy. Lamarck believed that

> . . . everything which has been acquired, impressed upon, or changed in the organization of individuals during the course of their life, is preserved by generation [heredity] and transmitted to the new individuals which have descended from those which have undergone those changes.

It is in this feature of Lamarck's theory that the greatest weakness lies.

Lamarck explained the development of a great many structures as a result of the inherited effects of use, for example, the webbed feet of ducks and geese, the long legs of wading birds, the tentacles of snails, the horns and hoofs of mammals, and the long neck of the giraffe. As a result of disuse he explained the limbless condition of snakes, the degenerate eyes of the mole, the absence of teeth in certain vertebrates, etc.

The idea of the inheritance of acquired characters was strongly opposed in 1883 by the German zoologist, August Weismann, whose views have largely influenced modern opinion. He held that, to be inherited, characters must arise in the germ cells, as these are the sole means of transmission between parent and offspring. Probably in all metazoans except the very lowest, germ cells are set apart early in development from undifferentiated embryonic cells and are not derived from specialized somatic tissues (see pp. 229–230 and Fig. 170). Thus, Weismann claimed, to cause a change in the next generation, external influences that later modify the soma must also affect the germ cells. There is no known mechanism, however, whereby modifications may be transferred from somatic tissues to gametes. This means that any induced change undergone by the soma has no racial effect because somatic cells do not become part of the next generation. So, according to Weismann, the inheritance of acquired characters is impossible.

Although it is true that the theory of the direct transmission of somatic modifications does explain the development of a great many structures, both progressive and retrogressive, many of these cases can be explained on some other basis. A more fundamental objection, however, is that the theory is unsupported by experimental work. Changes in organisms can be produced by use and disuse, mutilation, disease, or directly by the environment, but even after the causal agent has been operative for a great many generations, the induced effect disappears as soon as the cause is removed. In a few cases, however, there seems to be a permanent effect through "parallel induction." This means a simultaneous modification of the germ cells by the same influence that affects the soma but without any transfer from the latter to the former.

In conclusion, it may be said that, although Lamarck's theory seems plausible and is supported by some modern biologists, it is rejected by many because it rests upon an extremely unlikely assumption that is not supported by experimental work.

NATURAL SELECTION

The greatest name associated with the principle of organic evolution is that of the famous English naturalist, Charles Darwin (Fig. 270). Darwin did two things: (1) He accumulated

an overwhelming mass of evidence in support of organic evolution and thus proved its reality; (2) he proposed a theory, that of *natural selection*, to explain how evolution has taken place. His conclusions, based on over 25 years of investigation and study, were published in 1859 in "The Origin of Species," a book that has had a more profound influence on human thought than any other scientific work ever written. It was this book that resulted in the establishment of the principle of evolution as a fundamental scientific generalization.

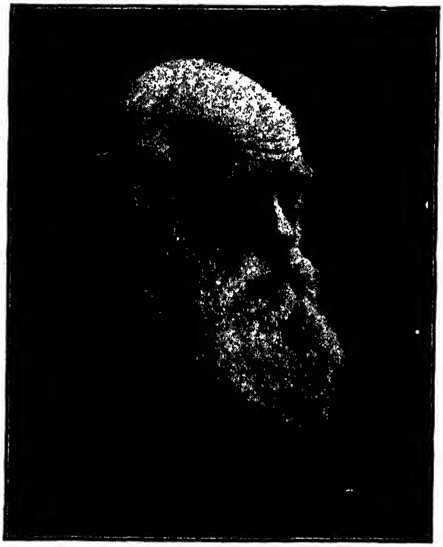


FIG. 270.—Charles Darwin, 1809–1882. (*From University Magazine. Photograph by Leonard Darwin.*)

Darwin's theory is based on several well-established facts and is itself merely a logical inference drawn from them.

Overproduction.—In 1798, Malthus published an essay in which he showed that human populations tend to increase in geometrical ratio—a rate greatly in excess of their means of sustenance. Darwin became impressed with this fact and saw that it applies to all living things. If an annual plant produces only 10 seeds, and if this rate continues in each generation and all the progeny live, at the end of 10 years there will be one billion descendants of the original plant. Of course, most plants produce many more than 10 seeds a year—some tens or even

hundreds of thousands. Similarly the number of young produced by some animals is enormous. For example, a single sturgeon may lay 2 million eggs a year, a cod 6 million, an oyster 60 million! Although these cases are extreme, it is perfectly true that the normal rate of reproduction in most species is of such magnitude that, if all the individuals produced were to live, in only a few generations the earth would not be large enough to hold them.

Competition.—Because of the limitations of available space and food, a great many more individuals are brought into existence than can possibly live to maturity. Consequently there follows a severe *competition,* called by Darwin "the struggle for existence," which acts as a check to the high rate of increase. In other words, organisms compete for an opportunity to live. Such competition may not necessarily involve a struggle to kill—an active combat—for it may be entirely passive. It may involve a struggle for room, for food and other necessities of life, or merely a struggle against adverse physical conditions of the environment. Most animals are destroyed while in a very young stage of development, many while still within the egg. This is why oviparous species must produce so many more offspring than viviparous ones. The seeds of most plants, falling into situations unfavorable for growth, do not even get a chance to sprout, while most of the seedlings that do develop never reach maturity because of competition with other plants for light, moisture, and other vital necessities.

Competition results in an *equilibrium of species.* It is a well-known fact that, where natural conditions remain undisturbed, approximately the same number of individuals of the same kind may be found in any given region from year to year. This means that, even with an enormously high rate of increase, competition is so severe that only enough individuals survive to replace the parents. Each species has established an equilibrium under its own set of environmental conditions, and this remains constant so long as disturbing factors do not arise. When man disturbs the balance of nature by killing off certain species, or by introducing foreign species to compete with the native ones, disastrous consequences often follow.

Variation.—The fact of *variation*—the tendency of individuals to differ from other members of their species—is of the utmost

importance, for without variation there could be no evolution. No two individuals are exactly alike, although it often requires critical examination and a thorough acquaintance with the organism to detect differences. Darwin did not distinguish clearly between heritable and non-heritable variations, but merely took the fact of variation for granted, and assumed that practically all organic differences are heritable.

Survival of the Fittest.—Darwin's theory of species formation is a logical inference based on the facts that have been presented. Infinitely more individuals come into existence than can possibly live, and this leads to a severe competition in which only a few survive. Because all members of any given species are highly variable, some may be better adapted to their environment than others. These individuals have an advantage over the rest and consequently are the ones to survive and to transmit their favorable variations to their offspring. Thus the best-adapted individuals are "selected" to survive and to leave progeny, while all of the others perish. Continuing generation after generation, this selective process is assumed to result in a gradual but steady modification of the characters of the species in the direction of better fitness to the environment.

This idea of "the preservation of the favored races in the struggle for life" was called by Herbert Spencer the *survival of the fittest.* Darwin called the process *natural selection,* because it was suggested to him after making an intensive study of the method used by man in the development of his numerous races of cultivated plants and domesticated animals, namely, the selection of certain individuals as the basis for the next generation and the elimination of the others, the selected individuals being those showing variations in some desired direction. This process Darwin called "artificial selection."

Under a constant set of environmental conditions, evolution by natural selection is gradual, but, when conditions change, new standards of selection are instituted and evolution is more rapid. Thus in a region undergoing a slight but persistent change in climate over a long period of time, organisms adapted to the old conditions would not be able to survive under the new ones. Only those individuals varying in the direction of greater fitness would leave offspring, and thus in time many new forms would come into existence and many old ones disappear.

Limitations of Natural Selection.—Granting that a selective process does occur in nature, and that the fittest survive, considerable question has been raised as to how far natural selection is adequate to explain the formation of new species. The fact that the theory has certain weaknesses was realized by Darwin himself. In fact, he considered natural selection to be not the exclusive factor in evolution but merely the chief factor. We shall consider here some of the most serious limitations of natural selection as a complete explanation of the origin of species.

Non-adaptive Characters.—Natural selection has been used to account for many striking cases of adaptation between organisms and their environment, and perhaps it is the most satisfactory explanation yet proposed of the origin of adaptive characters. It should be realized, however, that not all characters are useful, nor do they appear ever to have been useful in the organism's ancestry. Most species are distinguished from one another on the basis of slight, trivial, non-adaptive characters that apparently have no direct *survival value*, that is, they do not seem to give the organism any advantage in the struggle for existence. Any complete theory of evolution must account for all characters, not just adaptive ones.

Overspecialization.—On the basis of natural selection, it is difficult to understand cases of overspecialization—where structures have been developed far beyond their point of greatest utility. In many organisms, both living and extinct, evolution has gone so far that the individual is really handicapped in the struggle for existence. The extinct Irish elk, for example, which lived during the Pleistocene, had horns so large that they must have seriously interfered with its movements. The enormous curved tusks of the mammoths were similarly too highly specialized to have served their original function. Many paleontologists believe that overspecialization has been a most important factor in causing the extinction of species.

Origin of Variations.—It has long been realized, that, although natural selection may be effective in modifying characters already present, it cannot produce new ones. As commonly stated, the theory may explain the survival of the fittest, but it cannot explain the arrival of the fittest. It has been pointed out, however, that natural selection is not concerned with the origin of variations; it merely takes the existence of heritable variations

for granted, and then explains how they are preserved and modified.

Incipient Stages.—Not only is natural selection limited in its operation to characters already present, but it cannot act upon structures until they have developed sufficiently to have become useful. Otherwise it would give the organism no advantage in the struggle for existence. Structures such as wings, horns, and many others have no survival value until fully formed; in an undeveloped condition they are useless.

Heritability of Variations.—Although Darwin assumed that practically all variations are heritable, it has been found that many are not. With respect to their origin, two kinds of variations are now recognized: *germinal* and *somatic.* The former are determined by heredity, the latter by the environment. Because somatic variations are not heritable, selection based on them does not bring about a permanent change in the race and hence can have no evolutionary value. Thus selection, to be effective, must be confined to germinal variations.

Cumulative Effect of Selection.—Even when confined to germinal variations, selection is able to bring about only a very limited amount of change. Among a mixed population, selection in any given direction tends to create pure strains relatively uniform for the characters involved, but gradually selection becomes ineffective in producing further change. In other words, selection cannot proceed beyond the natural range of variability. For example, tall parents tend to produce tall offspring, and although a tall race will result from the continued mating of tall individuals, the tallest offspring will be no more extreme than those which occur among the general population. Selection may raise the general average but cannot transcend the limits of variability that already exist. It merely tends to isolate pure strains from a mixed population.

MUTATION

The mutation theory was announced in 1901 by Hugo de Vries, a Dutch botanist. It was based largely on a study of an American species of evening primrose, known as *Oenothera lamarckiana,* which had been introduced into Holland as a garden plant and was growing wild in the vicinity of Amsterdam. De Vries observed that, although most of the plants in the field were

typical in every way, a few were strikingly different, different enough in fact, to constitute new species (Fig. 271). He then took seeds from typical *lamarckiana* plants, sowed them in his botanical garden, and found that among the progeny there were

Fig. 271.—Lamarck's evening primrose (*Oenothera lamarckiana*, left) and one of its mutants (*O. gigas*, right), flower stalks, and rosettes. (*From de Vries, "Mutationstheorie," 1st ed., Von Veit & Company, and "Gruppenweise Artbildung," Gebrüder Borntraeger, Berlin, by permission.*)

always a relatively few new individuals each characterized by some striking peculiarity, such as smooth leaves, short styles, red veins, dwarf habit, tall habit, etc. These new individuals, of which de Vries found altogether about 12 different types, he called *mutants*. Further breeding revealed the fact that these mutants, for the most part, came true to type, and thus their

differences were constant. As a result of these studies, de Vries proposed the *mutation theory,* which suggested that new species appear suddenly, are distinct from the beginning, and are constant.

Continuous and Discontinuous Variations.—The outstanding difference between the theories of natural selection and mutation lies in the kind of variations that each emphasizes. Darwin considered that new species are formed by the gradual accumulation, through many generations, of numerous, small, intergrading variations under the influence of natural selection. De Vries, on the contrary, thought that new species arise suddenly and are distinct from the beginning. The variations that Darwin emphasized are called *continuous variations* or *fluctuations* because they vary about a standard, forming a graded series from one extreme to the other, as where a group of men are arranged in a line according to height. The variations that de Vries considered of prime importance are called *discontinuous variations* or *mutations* because they are not connected with each other by intergrades. Mutants have frequently arisen in plants and animals under domestication (see p. 282); in fact, de Vries thought that most new varieties have originated in this way.

Relation to Natural Selection.—The mutationists give natural selection a role in species formation, but one not so prominent as that ascribed to it by Darwin. They think that new species come into existence by the spontaneous appearance of mutants, but through the struggle for existence natural selection determines whether or not these new forms will survive. If better adapted to the environment than the parent species, they persist, but if not so well adapted, they are eliminated. In fact, most mutants are not so fit as the species from which they have arisen, and under natural conditions would not survive.

It should be understood that the factors responsible for the appearance of new characters by mutation are largely unknown. It seems certain that mutations arise from internal causes operating on the germ cells; yet the conditions under which they arise are not understood. Although it seems improbable that environmental factors are concerned with the appearance of mutations, it has been discovered, in both plants and animals, that gene mutations may be induced by treatment of germ cells with X rays, the changes appearing among the individuals of

the next generation. Such treatment results in mutations greatly in excess of the number that would otherwise appear.

Objections.—Two important objections have been raised against the mutation theory. (1) An objection that at once occurred to de Vries and has been more or less urged ever since is the possibility that *Oenothera lamarckiana* is a hybrid or at least an impure species—that the "mutants" are merely segregates arising from the "splitting" of a hybrid. De Vries observed that mutants appear in about 1.5 per cent of the progeny of *lamarckiana* plants, and, even if this ratio does not offer ready explanation according to Mendelian principles, nevertheless the possibility of the hybrid nature of this species exists. (2) Although the evening primrose studied by de Vries is unquestionably giving rise to new types, and although it has been found that a number of other plants and animals are behaving similarly, such cases are comparatively rare. In spite of the fact that a great many species have been studied, it must be admitted that most of them are not in a "mutating" condition. Thus, if mutation is not a general phenomenon, it can have but slight significance as a means of species formation.

CONCLUSIONS

The various theories that have been presented in an attempt to explain how the process of evolution operates represent a difference of opinion as to what are the most important factors involved. We have seen that no one theory is entirely adequate—each has its strong and weak points. Thus the method by which evolutionary changes have come about is still imperfectly understood. It seems certain, however, that several or many cooperating factors are involved, and that the problem of explaining the causes underlying racial changes in structure is of much greater complexity than the early students of evolution thought it to be. Although much progress is being made toward a solution of this great central problem of biology, a complete answer will not be forthcoming until a great deal more knowledge of plants and animals has accumulated.

Of the various evolutionary factors, some are primary or causative, while others are secondary or directive. To the former category belong variation and heredity, to the latter the environment and natural selection.

Causative Factors.—Since it is obvious that there could be no evolution without variation, a knowledge of the causes of variation and their manner of hereditary transmission is fundamental to any complete explanation of evolution. For this reason much modern research is being directed along these two lines. Although we have learned to differentiate between somatic and germinal variations and to recognize that it is probably only the latter that are of evolutionary value, our knowledge of the causes operative in the production of germinal variations is very meager. It seems rather certain, however, that they arise independently of the environment. The pioneer work of Mendel initiated an intensive study of the mechanism of hereditary transmission and has focused attention upon the chromosomes of the germ cells as the probable place where heritable variations originate.

Whether variations are continuous or discontinuous is of little consequence, for each kind may be either germinal or somatic. The important thing is to recognize that variations may be due to any one of three causes: (1) differences in environment or functioning; (2) recombination of hereditary characters or reappearance (segregation) of latent ones; (3) mutation. Somatic variations arise from the first cause, germinal variations from the other two. On the basis of outward appearance it is usually impossible to determine to which one of these three causes any given variation may be due; they can be distinguished only by breeding.

Mutations are heritable variations that are not due to segregation or recombination of characters. They apparently arise spontaneously in the germ cells from unknown causes. Mutations may be either large or small. The former, often involving several characters at once, are frequently due to the addition or loss of chromosomes in the germ cells arising from irregularities in their distribution at the time of reduction. Mutations of this sort, which are comparatively rare, are thought by some to give rise to new species directly. This is the method of evolution emphasized by de Vries. Small mutations, which are very common,[1] arise mostly as sudden changes involving individual genes, and it is this type of variations that forms the raw material for natural selection to work upon. It is they which are gradually

[1] For example, most of the heritable variations exhibited by the fruit fly (*Drosophila*) are of this type (Fig. 175).

accumulated and built into new species according to the Darwinian conception.

Directive Factors.—The general trend of evolution is toward greater fitness to the conditions of existence, and one of the great problems of biology is to explain adaptation. The history of life, as revealed by the fossil record, plainly teaches that there has been a marked correlation between changes in physical surroundings and the appearance of new types of organisms. Although this means that the environment is an important evolutionary factor, it does not imply that it is a direct one, as Lamarck and other early evolutionists assumed.

Both the theories of Lamarck and of Darwin deal with the development of adaptive characters, but the latter is generally considered to be by far the more adequate. According to the theory of natural selection, individuals that survive in the struggle for existence are, in general, those best adapted to their environment. Thus the environment determines survival but not fitness, the latter resulting from spontaneous variability arising from primary causes. The environment is an important directive factor, determining the course of evolution, but since it probably acts indirectly it cannot be a causative factor.

Selection is also not a causative factor because it cannot originate variations; it merely preserves and accumulates such as already exist, provided that they have survival value. In other words, natural selection determines which individuals, among a population exhibiting infinite diversity, shall be preserved. It is generally considered to be the most important directive factor yet discovered.

So far as the application of the selection principle to the racial improvement of man is concerned, it is certainly true, as Conklin says, that

> . . . the past evolution of the human race has been guided by the elimination of the unfit, whether physical, intellectual, or social, and the future progress of the race must depend upon this same process.

CHAPTER XXIII

THE EVOLUTION OF MAN

It has long been realized that the human body is constructed on the same general plan as that of other mammals, that it comes into existence, grows, and is nourished in the same way, and that it is subject to the same natural laws that apply to other organisms. Therefore whatever causes have played a part in the evolution of other animals have also been operative in the derivation of the human species from a more primitive ancestor.

Distinctive Features of Primates.—On the same basis that the dog is classified with the carnivores and the horse with the ungulates, *viz.*, fundamental structural resemblance, man must be placed in the primate group—that order of mammals which includes the lemurs, monkeys, and apes. The remarkable complexity of the brain, which reaches its culmination in man, is perhaps the most outstanding feature of the primates, but although surpassing all the other mammals in mental development, physically they have remained primitive.

Primates are plantigrade mammals with pentadactyl limbs, the digits typically being furnished with nails. The hands, and in most cases the feet as well, are prehensile, the first digit being more or less opposable to the others. Like the limbs, the teeth are also relatively unspecialized. In the lower monkeys 36 teeth are present (Fig. 209), but in all the higher primates there are 32 (Figs. 277 and 287). A clavicle (collarbone) is always present in the pectoral girdle; this is also a primitive feature. The stomach is simple. The mammae occupy a thoracic position, only one pair being present. As a rule the young are born singly and are completely helpless during early infancy. Primates are largely herbivorous and, with the exception of man, the gorilla, the baboons, and some of the Old World macaques, arboreal in their habits. All but man, whose range has become considerably extended through artificial adaptation, are confined to warm regions.

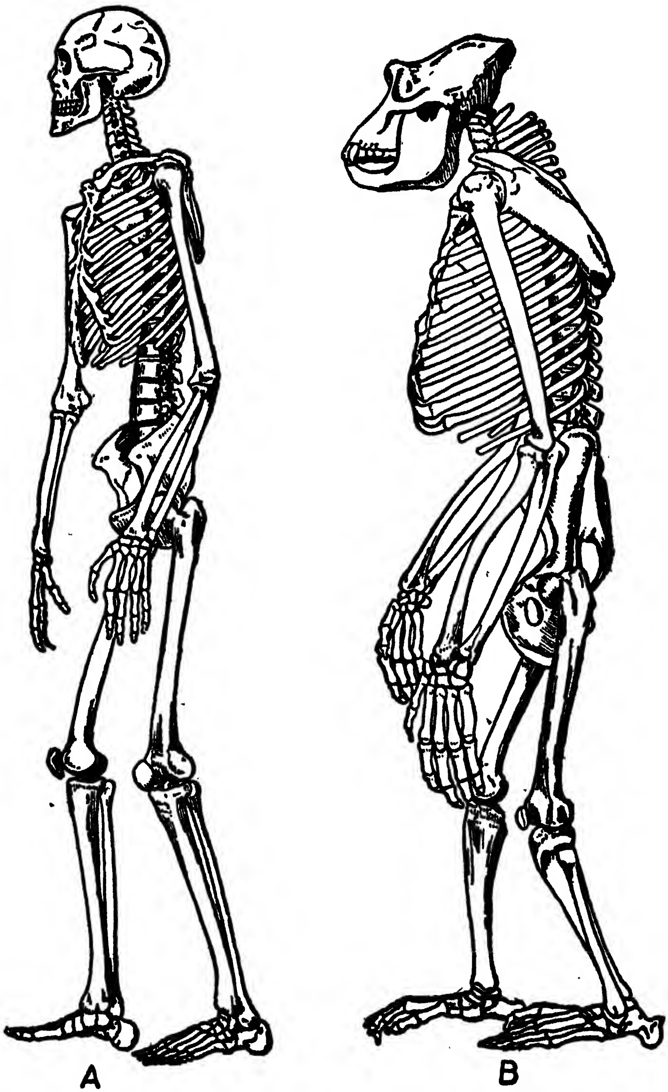


FIG. 272.—Skeletons of man and gorilla. The general fundamental similarity is striking, the differences being mostly in details. Among these, note the size and shape of the cranium, of the teeth, and of the lower jaw; the relative length of the arms and legs; the curvature of the spine; the position of the great toe. (*From Lull, "Organic Evolution," The Macmillan Company, by permission.*)

The primates include six well-defined families: the lemurs (Lemuridae), the marmosets (Hapalidae), South American monkeys (Cebidae), Old World monkeys (Cercopithecidae), the anthropoid apes (Simiidae), and mankind (Hominidae). The lemurs comprise the lowest group, the anthropoid apes the group

FIG. 273.—The gibbon, the most primitive of the anthropoids in regard to certain characters of the skull and teeth but with limbs highly specialized for arboreal life. When on the ground it walks erect. (*Courtesy of the New York Zoological Society.*)

most closely related to man. In fact, the structural resemblances between the two highest families are much greater than between the anthropoid apes and the lower primates (Fig. 272). All the races of modern man are considered to belong to the same species—*Homo sapiens*—but three main varieties are commonly recognized: the Ethiopian, Mongolian,[1] and Caucasian.

[1] Although the American Indian is sometimes separated as a fourth variety, it is usually included under the Mongolian.

The Anthropoid Apes.—The four anthropoid apes, comprising the gibbon, orangutan, chimpanzee, and gorilla, are distinguished from the other primates by several important characters: (1) All are tailless; (2) the number of teeth is the same as in the Old World monkeys and in man, both in the temporary and

Fig. 274.—The orangutan, a brown-haired anthropoid native of Borneo and Sumatra. The skull is higher and more rounded and the face much longer than in the gibbon. (*Courtesy of the New York Zoological Society.*)

permanent sets; (3) the arms are much longer than the legs; (4) when on the ground they can assume a semierect position on the hind limbs; (5) the thumb is short, but the great toe is well developed and opposable; (6) all are much more intelligent than the lower primates, the brain being more highly developed.

The gibbon and orangutan are found in southern Asia, the chimpanzee and gorilla in tropical Africa (Figs. 273 to 276). The gibbon is the smallest of the anthropoids, rarely exceeding

3 feet in height, while the gorilla is the largest and most powerful, the male attaining an average height of about 5½ feet and a weight of approximately 400 pounds. The gibbon is the only form that habitually walks erect when on the ground, but the others can do so by touching the knuckles to the ground in order

FIG. 275.—The chimpanzee. Note the protruding jaw and very prominent eye arches. The arms are longer than the legs, but relatively shorter than those of the gibbon and orangutan. (*Courtesy of the New York Zoological Society.*)

to maintain their balance. The skull of the gibbon is smooth on the top and does not have bony arches over the eyes, but in the other anthropoids the skull bears a median crest, and the eye arches are prominent (Fig. 277). In the chimpanzee and gorilla the canine teeth are conspicuous, in the latter being developed as short tusks.

Distinctive Features of Man.—Man is distinguished from the anthropoid apes and other primates chiefly by the following

characters: (1) The brain, especially the cerebrum, is notably larger and more complex; (2) the face is short and nearly vertical; (3) the lower jaw bears a distinct chin; (4) all the teeth are reduced in size, the canines being not larger than the others; (5)

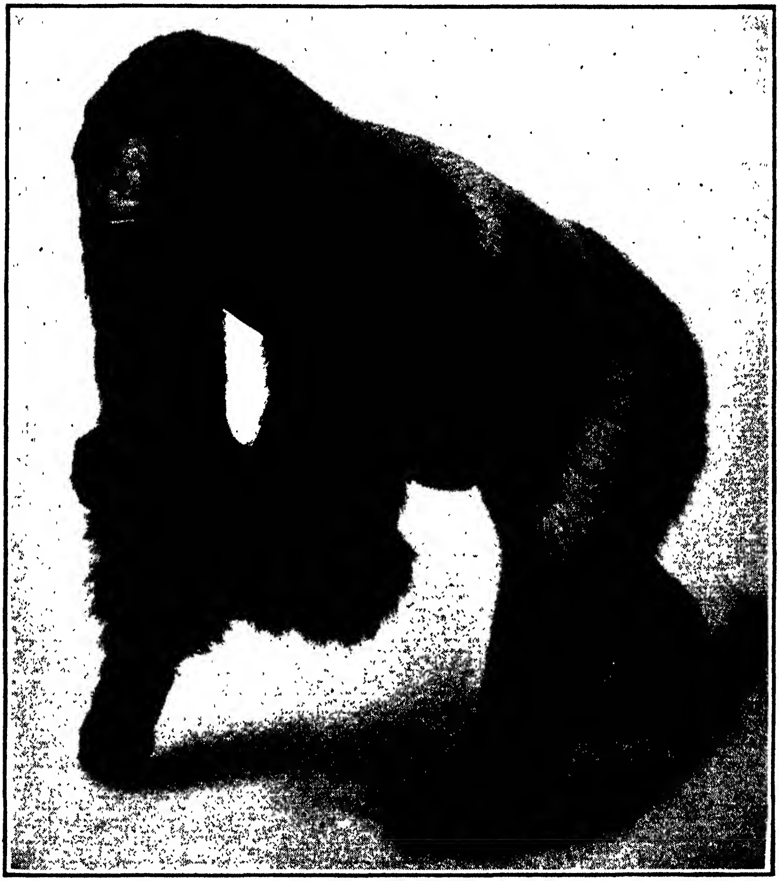


FIG. 276.—Mounted specimen of male gorilla, the largest of the anthropoid apes, and in many ways the most highly specialized. (*Courtesy of the Field Museum of Natural History, Chicago.*)

the spinal column, adapted to erect posture, has four distinct curves; (6) the arms are not so long as the legs; (7) the thumb is freely opposable, but the great toe is not; (8) the power of articulate speech is fully developed.

The differences between man and the anthropoid apes are chiefly associated with the assumption of the erect posture and

the development of the brain. With the gradual abandonment of arboreal life and the growing ability to walk erect with ease, it became possible for the precursors of man to make freer use of the hands, a most important factor in early human evolution. For example, the early employment of tools and weapons, correlated with increasing mental powers, marked the beginning of man's supremacy over the other mammals. Related to the development of the erect posture were such structural changes as the broadening of the pelvis, straightening of the spine, shorten-

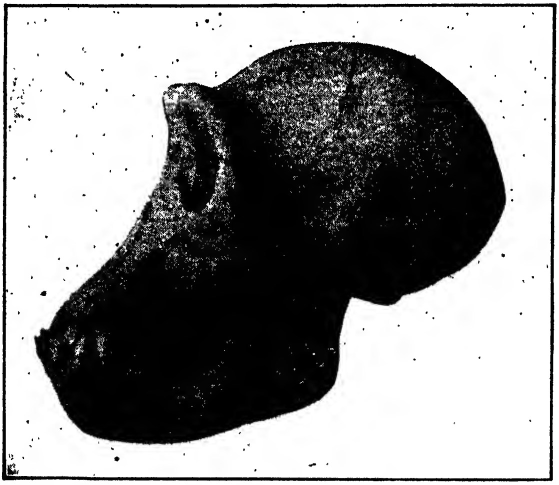


FIG. 277.—Skull of chimpanzee, $\times \frac{1}{3}$. Note the very retreating forehead, the prominent eye arches, the flat nose and protruding jaw, the large canine teeth, and the absence of a chin.

ing of the arms, modified position of the head on the spinal column, etc. Associated with the development of the brain was the growing power of articulate speech, at first feebly manifested, but gradually enabling primitive man to communicate by means of language.

History of the Primates.—It will be recalled that the mammals began their ascendancy at the beginning of the Cenozoic era and soon gave rise to many diverse groups. According to prevalent scientific opinion, the carnivores and primates had a common origin, most likely in a primitive stock of insectivores. In fact, during the Paleocene there existed in North America and Europe a group of small arboreal mammals intermediate between the

tree shrews (insectivores) and lemurs (primates). These forms may have been ancestral to the entire primate line.

The primates became differentiated as a distinct order of mammals during the Eocene. The fossil record shows that

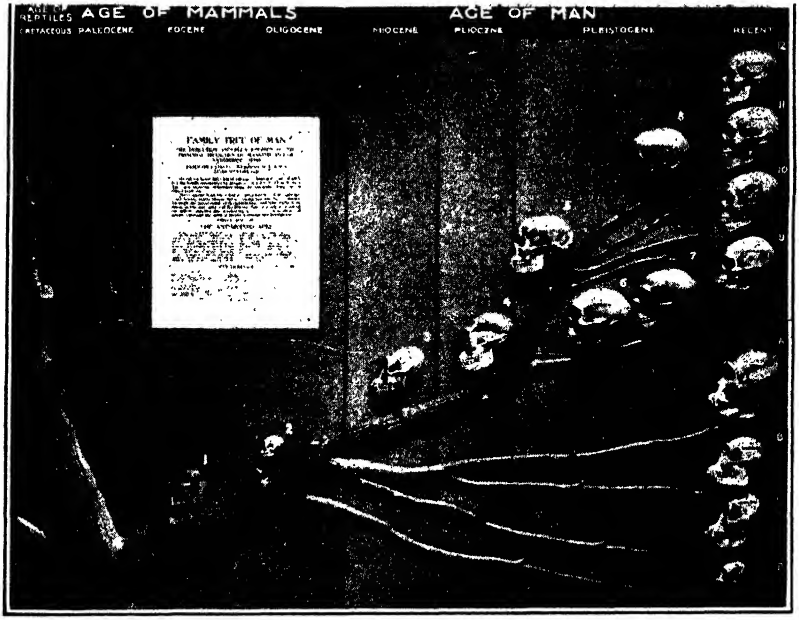


FIG. 278.—Family tree of man, showing the evolution and relationships of the principal branches of mankind and of the anthropoid apes. 1, Primitive primate (*Notharctus*) from the Eocene of Wyoming; 2, Prototypal anthropoid (*Propliopithecus*) of Oligocene age, from Egypt; 3, Primitive anthropoid (*Dryopithecus*) from the Miocene of India; 4, Ape man (*Pithecanthropus*) of Java; 5, Piltdown man (*Eoanthropus*); 6, Heidelberg man (*Homo heidelbergensis*); 7, Neanderthal man (*Homo neanderthalensis*); 8, Cro-Magnon man (*Homo sapiens*); 9, Australian black man, one of the most primitive of existing human races; 10, Hottentot, representing the Negro group of races; 11, Chinese, representing the Mongolian races; 12, American, representing the Caucasian group; *A*, gorilla; *B*, chimpanzee; *C*, orangutan; *D*, gibbon. (*Courtesy of Professor William K. Gregory and the American Museum of Natural History.*)

primitive lemurs of many kinds lived in North America and Europe at that time. One of these (*Notharctus*) is shown in Fig. 278. In the Oligocene deposits of northern Egypt several different kinds of primates have been found intermediate between these primitive Eocene lemurs and the monkeys and apes of later times. One of them (*Propliopithecus*, Fig. 278) was probably a direct ancestor of the gibbons, while the others are considered to have been forerunners of the Old World monkeys. Remains of the

latter group are represented in the Miocene, Pliocene, and Pleistocene formations of Europe, Asia, and Africa.

The first true anthropoids are recorded in the Miocene and Pliocene rocks of Europe and India. Some authorities regard them as ancestral to modern anthropoids but not to man. Others think that one form (*Dryopithecus*, Fig. 278) may represent a common Miocene stock from which both man and the higher apes arose. Substantiating this view is the fact that, during the Miocene and early Pliocene, increasing aridity, especially in central Asia—to which evidence points as the place of origin of the human stock—caused a gradual disappearance of forests, and it has been suggested that this may have been the impelling cause of the origin of man, his immediate ancestors being forced to abandon arboreal existence and slowly to adopt a terrestrial mode of life in a progressively more open country.

The Quaternary period, of about 1 million years duration, has been called the "Age of Man," as it was during the Pleistocene that man began to rise in supremacy over the other mammals, and today, of course, he dominates the earth. The Pleistocene epoch was characterized by the development of enormous continental glaciers that appeared at intervals as a consequence of great climatic changes. In Europe, four distinct invasions of the ice occurred, separated by intervening warm periods, and so it is customary to divide the Pleistocene of Europe into four glacial and three interglacial stages.

We are now ready to consider briefly some facts regarding the earliest races of mankind. Our knowledge is based on fossils that have been found, for the most part, in river valley deposits or in caves. Although we shall consider these races in the order of their probable age, it should not be assumed that they form a single evolutionary series. In fact, it is generally agreed that they probably represent several divergent lines of descent (Fig. 278).

The Java Ape Man.—In 1891 there was discovered in a river deposit in central Java, associated with the bones of extinct mammals, the remains of a creature that has been given the name of *Pithecanthropus erectus* (Figs. 279 and 280). These remains consist of a skull cap (roof of the skull) two upper molar teeth, and a femur (thigh bone). The age of the deposit in which they were found was at first supposed to be late Pliocene

but was later established as very probably early Pleistocene. Some authorities think that *Pithecanthropus* lived still later, possibly during the middle Pleistocene.

The skull cap is very long in proportion to its breadth and is narrow in the frontal region, in the latter respect resembling

Fig. 279.—*Pithecanthropus erectus*, the ape man of Java, as restored by Professor J. H. McGregor, Columbia University. Antiquity estimated at about 1 million years. (*Courtesy of Professor McGregor.*)

that of the chimpanzee. The brain capacity has been estimated at 900 cubic centimeters, that of the male gorilla never exceeding 600 cubic centimeters, while that of the lowest members of the human race (the native Australians) is about 1,300 cubic centimeters. The average brain capacity of the white race is approximately 1,500 cubic centimeters and the maximum almost 2,000 cubic centimeters. *Pithecanthropus* had a very low, retreating forehead and prominent eye arches, the latter being almost as

conspicuous as those of the chimpanzee. Judging from the slope of the forehead, it is probable that the jaw protruded greatly. The teeth are intermediate in structure between those of modern man and the apes. If the femur belonged to the same individual, as seems probable, the creature was about 5 feet 7 inches tall and walked erect.

FIG. 280.—Side and top views of the skull cap of *Pithecanthropus erectus*, × 1/3. Note its narrowness, especially in the frontal region, the heavy eye arches, and the retreating forehead. (*From Osborn, "Men of the Old Stone Age," Charles Scribner's Sons, after Du Bois, by permission.*)

Most authorities regard *Pithecanthropus* as collaterally related to modern man, and so not in the direct line of descent. From a study of plant and animal fossils later found in the same deposit from which the *Pithecanthropus* remains were obtained, it has been determined that the Java ape man was a forest-dwelling type, probably having migrated from a more northern region. Hence he was out of competition with his more progressive contemporaries, which we assume existed on the central Asiatic

plains, and remained primitive in an environment where living was easy.

The Peking Man.—The Peking man (*Sinanthropus pekinensis*), whose remains have been recently found in a cave deposit at Chow Kow Tien, near Peiping (formerly Peking), China, is

FIG. 281.—Side and top views of the cranium of the Peking man (*Sinanthropus pekinensis*), × ⅓. Compare with Fig. 280. (*From G. Elliot Smith in Scientific Monthly.*)

another primitive type similar in many respects to *Pithecanthropus* but generically distinct. The remains consist of parts of 10 different skulls, including teeth and jaw fragments, the most remarkable discovery, made in 1929, being an almost complete uncrushed cranium (Fig. 281). The remains of more than 50 different types of mammals, besides other vertebrates, were associated with the *Sinanthropus* material, all of which belong to

the very early Pleistocene. Thus there is no doubt as to when the Peking man lived, and if our geologic time scale is correct, these remains are a million years old.

In form of skull and size of brain, *Sinanthropus* shows a striking similarity to *Pithecanthropus*, but, while primitive, is of a dis-

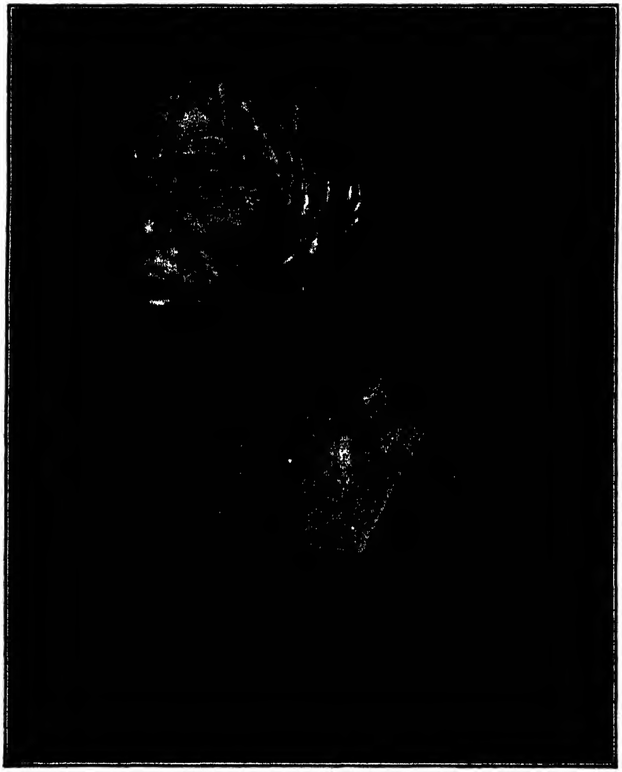


FIG. 282.—The Piltdown man of Sussex, England, as restored by Professor J. H McGregor. (*Courtesy of Professor McGregor.*)

tinctly higher type. The cranial capacity is approximately 1,000 [illegible]meters. Although the roof of the skull is slightly higher than that of *Pithecanthropus*, it is only three-fourths as high as in modern man. The skull is narrow in front and provided with very prominent eye arches. One of its most distinctive features is the exceptional thickness of the cranium. In this respect, as well as in the ape-like character of the jaw, the Peking man resemb[illegible] to be considered.

The Piltdown Man.—The Piltdown man (*Eoanthropus dawsoni*) was first known from a single broken skull and jawbone found in 1912 at Piltdown, Sussex, England. The age of the material is uncertain, having been ascribed to the middle Pleistocene (third interglacial stage) by some, to the early Pleistocene (first or second interglacial stage) by others, while recent evidence indicates that its age may be late Pliocene. The remains were found in association with the bones of extinct mammals and with some very primitive bone and flint implements.

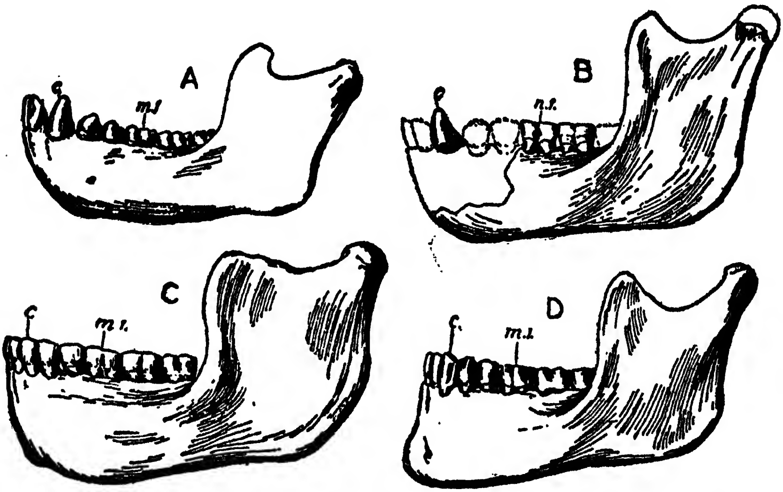


FIG. 283.—Side view of jaws of chimpanzee (*A*), Piltdown man (*B*), Heidelberg man (*C*), and modern man (*D*). (*From Woodward, "Guide to the Fossil Remains of Man," British Museum, by permission.*)

The skull of the Piltdown man measures 11 to 12 millimeters in thickness, that of the existing native Australians being 6 to 8 millimeters, and of modern Europeans only 5 to 6 millimeters. In fact, the skull is exceeded in thickness only by that of the Peking man. The forehead is high and prominent and is without conspicuous eye arches (Fig. 282). The cranial capacity has been variously estimated at 1,000 to 1,500 cubic centimeters. The primitive character of the Piltdown man is revealed particularly in the character of the lower jaw and the teeth. The former is without a chin and is almost identical with that of a young chimpanzee (Fig. 283). The teeth are human, but the canines are very conspicuous. Some authorities have considered the skull to belong to a primitive man, but the jaw to an extinct

ape, claiming that their association was accidental. A few years after the original discovery, however, a portion of another skull and a tooth similar to that present in the first jaw were found in the same region, so that there remains little doubt but that the skull and jaw belong to the same individual.

The Heidelberg Man.—The Heidelberg man (*Homo heidelbergensis*) lived in Europe probably during the second interglacial period. He is known only from a single lower jaw discovered in 1907 in southern Germany near Heidelberg (Figs. 283 and 284). The jaw was found in a river deposit 79 feet below the level of the ground. From the same formation have

FIG. 284.—The Heidelberg jaw, about × ⅔. (*From Osborn, "Men of the Old Stone Age," Charles Scribner's Sons, after Schoetensack, by permission.*)

been obtained the bones of many extinct mammals. The Heidelberg jaw is very large and heavy and, as in the Peking and Piltdown jaws, lacks the projecting point that forms the chin of modern man. In fact, were it not for the teeth, which are all distinctly human (albeit somewhat primitive in form), the jaw would have been regarded as that of an extinct anthropoid ape.

The Neanderthal Man.—The Neanderthal race (*Homo neanderthalensis*) is known from a number of specimens found mostly in caves in about 20 different localities in Europe. The first specimen, a skull cap, was discovered in 1856 in the Neander Valley, near Düsseldorf, Germany. Later many skeletons and more complete skulls were found elsewhere in Europe, particularly in southwestern France. The Neanderthal race lived during the third interglacial and fourth glacial stages and is thought

to have occupied Europe for at least 50,000 years—perhaps twice as long.

The Neanderthals were a low-statured people, the males rarely exceeding 5 feet 5 inches in height. The head protruded slightly forward from the broad rounded shoulders. The limbs were

FIG. 285.—Head of the Neanderthal man, modeled by Professor J. H. McGregor. This primitive race inhabited Europe 25,000 to 75,000 years ago. (*Courtesy of Professor McGregor.*)

short and thick, the knees being slightly bent forward as a result of the curvature of the thigh bones. They walked with a stooping gait, the erect posture that characterized subsequent races not being fully established. The skull was thick, long, and narrow, with a retreating forehead and a broad flat nose (Figs. 285 and 286). The eye arches were thick and very prominent. The lower jaw and the teeth were primitive, the former being

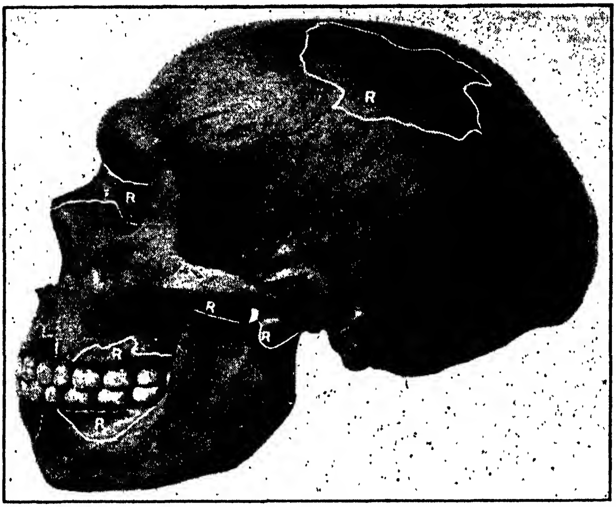


FIG. 286.—Photograph of a cast of a Neanderthal skull found at La Chapelle-sux-Saints, Corrèze, France, in 1908, with the missing parts (*R*) restored by Professor J. H. McGregor, × ⅓. Note the low forehead, the heavy eye arches, and the primitive jaw. (*Courtesy of Professor McGregor.*)

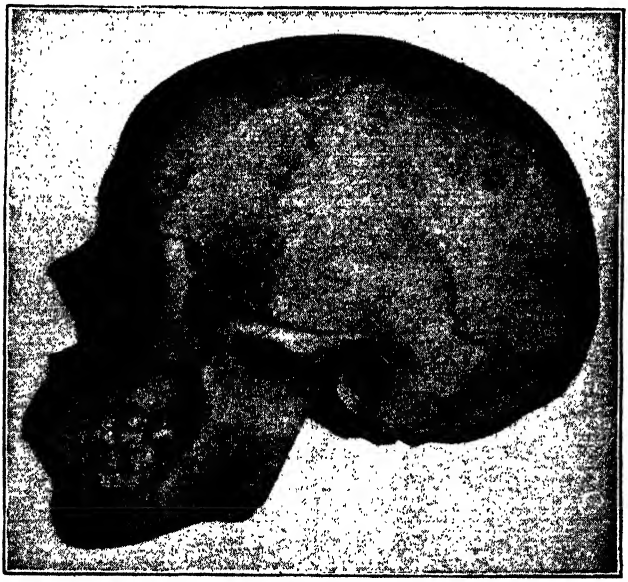


FIG. 287.—Skull of modern man (*Homo sapiens*), × ⅓. Compare with Figs. 277 and 286.

less powerful than that of the Heidelberg man, but yet relatively thick and heavy. In some individuals the chin was slightly developed but in most cases was absent. The teeth were more primitive than in modern races, but the canines were not so conspicuous as in the Piltdown man. The cranial capacity of the Neanderthals rarely exceeded 1,500 cubic centimeters, this being the same as that of the average modern Caucasian. The proportions of the brain were different, however, the frontal portion, which is the seat of higher faculties, being relatively smaller and the convolutions simpler.

The Neanderthals were a cave-dwelling race. They made use of primitive flint tools and weapons, and hunted such animals as wild horses, cattle, reindeer, and cave bears. The association of fire-charred bones of these animals with Neanderthal remains shows that these primitive people knew the use of fire. Whether the Neanderthals became entirely extinct or partly evolved into the lower races of modern man is an unsettled question, but at any rate they were succeeded by a vastly superior type of people who came probably from Asia at the beginning of post-glacial time—approximately 25,000 years ago.

The Cro-Magnon Man.—This highly developed race, belonging to *Homo sapiens*, seems to have undergone its early evolution in Asia, but migrated into Europe and gradually replaced the Neanderthals. A number of complete skeletons have been found in various parts of Europe, chiefly in caves. The first specimens were discovered at Cro-Magnon, France. These people were physically one of the most splendid races of man that has ever existed. They were tall in stature, the males averaging slightly over 6 feet in height. The skull was large but narrow, with a broad face and high check bones (Fig. 288). The forehead was high and the eye arches small or absent. The lower jaw was heavy but was provided with a conspicuous chin. In development, the brain was essentially modern, being larger, in fact, than that of the modern white race. In some cases the cranial capacity was as much as 1,800 cubic centimeters.

The Cro-Magnons were a race of cave-dwelling hunters, and although their stage of culture probably did not surpass that of some existing savages, intellectually they were vastly superior to the Neanderthals. Indeed, they were an artistic people, ornamenting the walls of their caves with sculpture, drawings,

and even with colored paintings. They are thought to have persisted in Europe for at least 10,000 years. Finally, however, they declined and became supplanted by four or five new races that came in probably from Asia, bringing with them a higher

FIG. 288.—Head of the Cro-Magnon type of *Homo sapiens*, a race inhabiting southwestern Europe about 25,000 years ago. Restoration by Professor J. H. McGregor. (*Courtesy of Professor McGregor.*)

culture, just as the Cro-Magnons themselves had done earlier. Elements of these new races are found among modern Europeans. Although largely replaced by the races that succeeded them, to some extent they may have been absorbed by them.

Since the time of the Cro-Magnons, human progress has been almost entirely intellectual and social. Lull says:

Man's physical evolution has virtually ceased, but in so far as any change is being effected, it is largely retrogressive. Such changes are: reduction of hair and teeth, and of hand skill; and dulling of the senses of sight, smell, and hearing upon which active creatures depend so largely for safety. That sort of charity which fosters the physically, mentally, and morally feeble, and is thus contrary to the law of natural selection, must also in the long run have an adverse effect upon the race, unless offset by an enlightened eugenics . . . His future evolution, in so far as it is progressive, will be mental and spiritual rather than physical, and as such will be the logical conclusion of the marvellous results of organic evolution.

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(References in **boldface** type indicate pages on which illustrations appear.)

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